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of the
American Association *of* Petroleum Geologists

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Volume 25 Number 1

BULLETIN
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AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

JANUARY, 1941

MAJOR TECTONIC PROVINCES OF SOUTHERN OKLAHOMA AND THEIR RELATION TO OIL AND GAS FIELDS[1]

E. A. PASCHAL[2]
Amarillo, Texas

ABSTRACT

Southern Oklahoma and adjoining areas are divided into five tectonic provinces. One is considered a part of the Appalachian-Ouachita-Marathon homogeneous mobile belt which extends across the continent. The other four are considered as having the features of a heterogeneous mobile belt. They are treated as two "uplifts" and two "geosynclines" and are compared with similar provinces in California.

Evidence is presented to show that one of the geosynclines has been compressed or squeezed between the two adjoining uplifts since the deposition of the Permian redbeds. The local structures within the geosynclines are considered as having been formed primarily by compression, whereas the local structures on the uplifts are considered as having been formed by "vertical uplift." The local structures on the two uplift provinces are considered as having possibilities of more prolific oil production, especially from Ordovician beds, than the local structures within the geosynclines.

INTRODUCTION

Figure 1 presents the writer's conception of the location and approximate boundaries of the major tectonic provinces of southern Oklahoma and adjoining areas. They are from east to west: the Ouachita Mountains province; the Arkansas Valley geosyncline; the Hunton-Tishomingo uplift; the Anadarko-Ardmore geosyncline; and the Amarillo-Wichita-Red River uplift. The granite shown by symbol in Figures 1, 2, and 3 in Oklahoma crops out in the Arbuckle and Wichita Mountains and is reproduced from the geologic maps of the United States[3] and of the state of Oklahoma.[4] The granite in northern Texas (Fig. 1) is that encountered in drilling wells as shown by Sell-

[1] Manuscript received, July 31, 1940.

[2] Coline Oil Corporation.

[3] "Geologic Map of the United States," *U. S. Geol. Survey* (1932).

[4] "Geologic Map of Oklahoma," *ibid.* (1926).

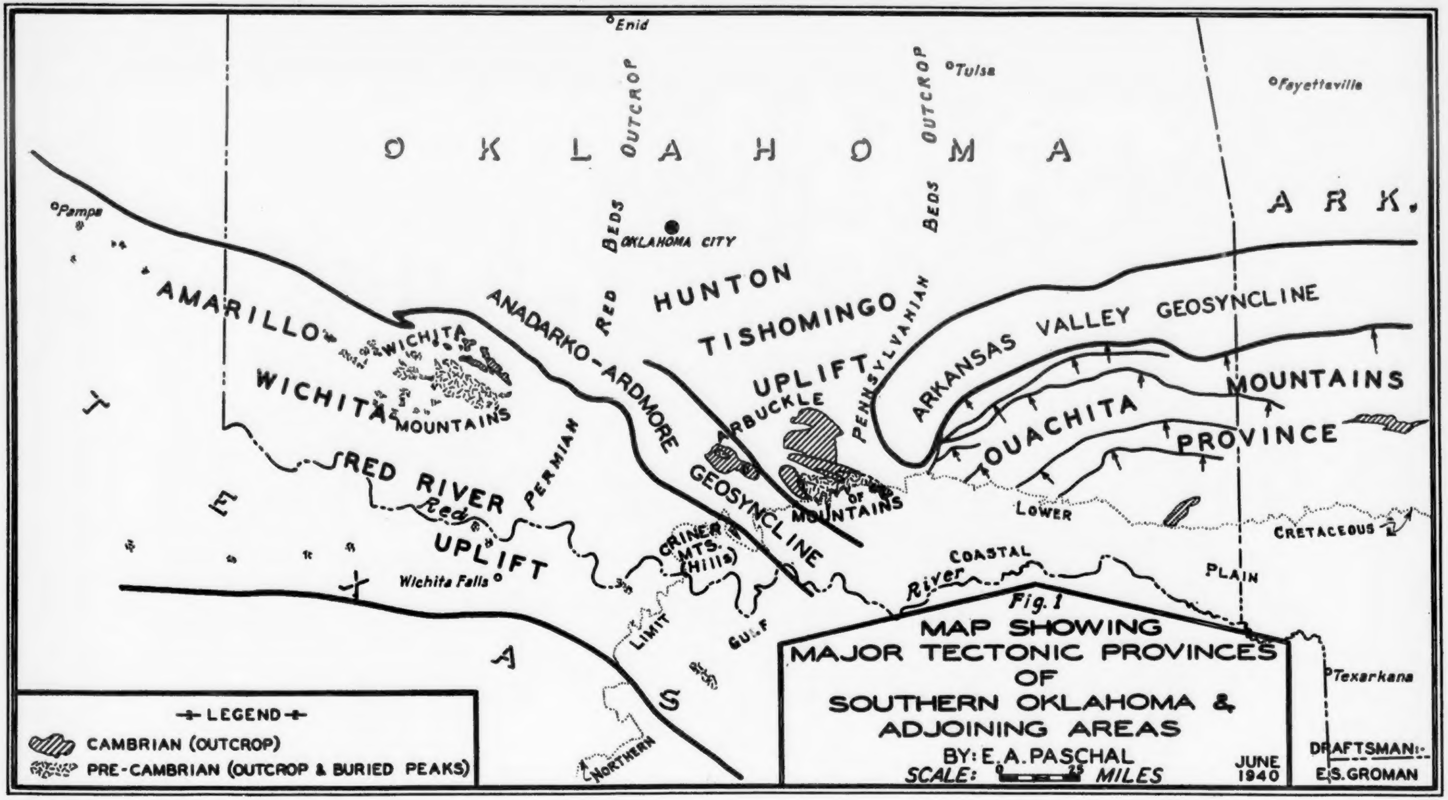
Fig. 1
MAP SHOWING
MAJOR TECTONIC PROVINCES
OF
SOUTHERN OKLAHOMA &
ADJOINING AREAS
BY: E. A. PASCHAL
SCALE: 0 25 MILES
JUNE 1940
DRAFTSMAN:-
E.S. GROMAN
LEGEND
CAMBRIAN (OUTCROP)
PRE-CAMBRIAN (OUTCROP & BURIED PEAKS)
OKLAHOMA
ARK.
TEXAS
Enid
Tulsa
Fayetteville
Pampa
OKLAHOMA CITY
Wichita Falls
Texarkana
RED BEDS OUTCROP
PENNSYLVANIAN BEDS OUTCROP
PERMIAN
AMARILLO
WICHITA
WICHITA MOUNTAINS
ANADARKO-ARDMORE GEOSYNCLINE
RED RIVER UPLIFT
Red River
HUNTON
TISHOMINGO
UPLIFT
ARBUCKLE
MOUNTAINS
CRINER MTS. (Hills)
ARKANSAS VALLEY GEOSYNCLINE
OUACHITA MOUNTAINS PROVINCE
LOWER CRETACEOUS
COASTAL PLAIN
GULF
NORTHERN LIMIT

FIG. 1

ards[5] and represents areas where it lies immediately below Pennsylvanian beds.[6] The granite in the Texas Panhandle (Fig. 1) was also encountered in drilling wells as shown by Rogatz[7] and described by him as being buried peaks which pierce the overlying Permian strata.[8] The Cambrian in Figure 1 and Cambro-Ordovician in Figures 2 and 3, shown by symbol, crop out in the Ouachita, Arbuckle, Criner, and Wichita mountains and are here reproduced from the geologic maps of the United States and Oklahoma. The Paleozoic is not further differentiated. Except for the narrow belts within and around these mountains most of the surface of the area here under consideration consists of Pennsylvanian in the east part and Permian in the west. The location shown for the northern limit of the Lower Cretaceous of the Gulf Coastal Plain was taken from the geologic maps of the United States and Oklahoma.

NAMING OF PROVINCES

The name "Arkansas Valley" has been adopted from Croneis[9] who used it to designate the province between the Ozark highland and the Ouachita province in eastern Oklahoma and western Arkansas. The name "Hunton-Tishomingo" has been adapted from Dott[10] who used it to designate the uplift known to geologists as the Arbuckle Mountains, forming the eastern part of the area in central Oklahoma in which the pre-Cambrian and lower Paleozoic rocks crop out. The name "Anadarko-Ardmore" combines two provinces commonly designated by those names into one, as suggested by van der Gracht[11] and van Weelden.[12] This designation is considered as better applied to the province, as here described, than the name "Ardmore-Arbuckle geo-

[5] E. H. Sellards, "Structural Map of Texas," *Bur. Econ. Geol. Bull. 3401* (2d ed. revised, January, 1939).

[6] *Bur. Econ. Geol. Bull. 3401* (1934), p. 94.

[7] Henry Rogatz, "Subsurface Geological Map of Texas Panhandle Oil and Gas Field," *Oil Weekly*, Vol. 92, No. 4 (January 2, 1939), supplement.

[8] Henry Rogatz, "Geology of the Texas Panhandle Oil and Gas Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (July, 1939), p. 986.

[9] Carey Croneis, "Natural Gas in Interior Highlands of Arkansas," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), Fig. 1, p. 534.

[10] Robert H. Dott, "Overthrusting in the Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), pp. 567–602.

[11] W. A. J. M. van Waterschoot van der Gracht, "The Permo-Carboniferous Orogeny in the South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 991–1057. Also *Royal Acad. Sci. Amsterdam*, Sec. 11, Vol. 47, No. 3, pp. 1–170. See especially Pl. I of the last reference.

[12] A. van Weelden, "Regional Tectonic Features of the Wichita-Arbuckle Mountain Region in the Light of Geophysical Observations," *Oil Weekly*, Vol. 70 (September 11, 1933), pp. 27–30.

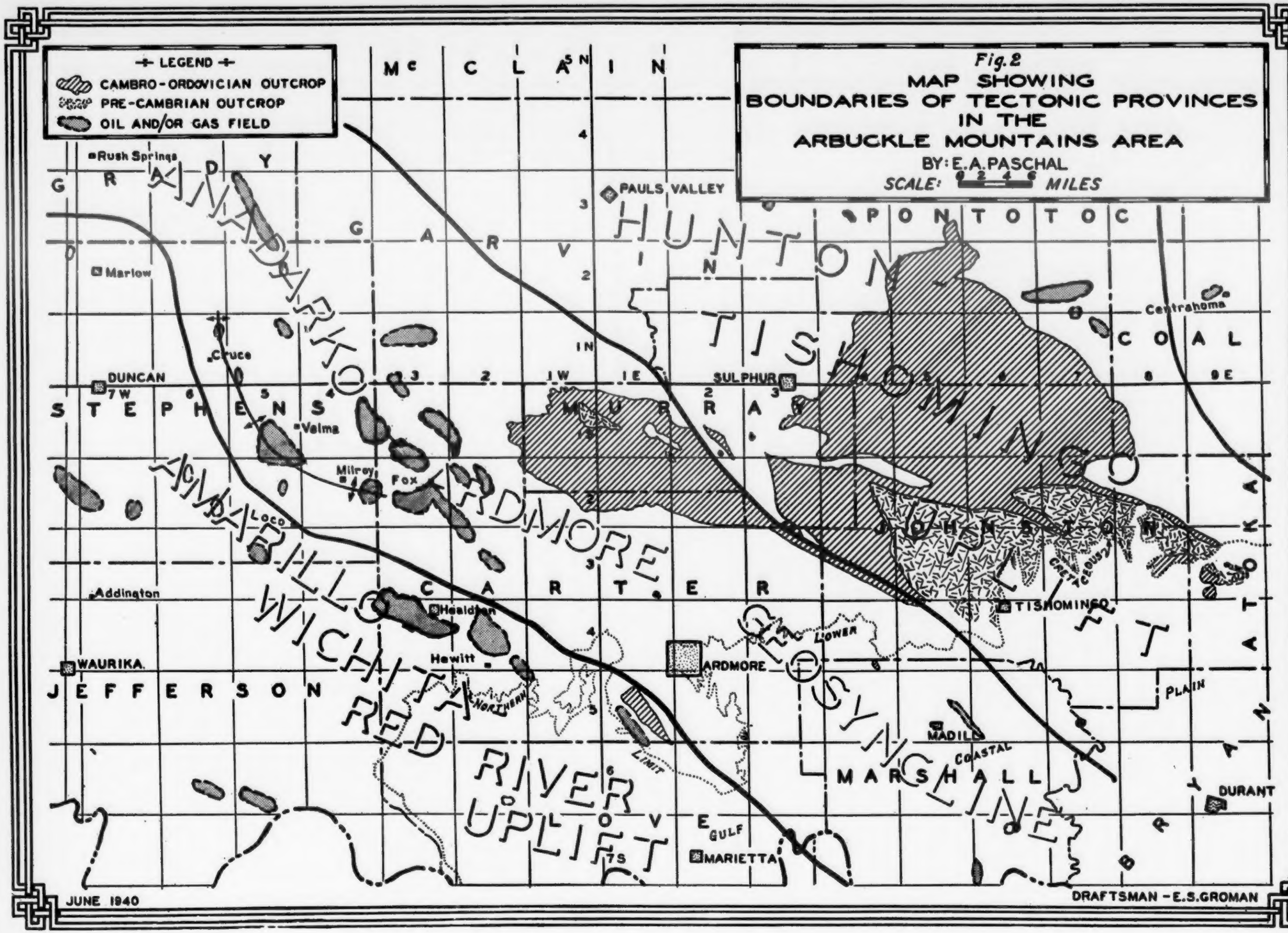
Fig. 2
MAP SHOWING
BOUNDARIES OF TECTONIC PROVINCES
IN THE
ARBUCKLE MOUNTAINS AREA
BY: E.A. PASCHAL
SCALE: 0 2 4 6 MILES
LEGEND
CAMBRO-ORDOVICIAN OUTCROP
PRE-CAMBRIAN OUTCROP
OIL AND/OR GAS FIELD
ANADARKO
ARDMORE
AMARILLO
WICHITA
RED RIVER UPLIFT
HUNTON
TISHOMINGO
UPLIFT
SYNCLINE
McCLAIN
GRADY
GARVIN
PONTOTOC
COAL
STEPHENS
MURRAY
CARTER
JOHNSTON
JEFFERSON
MARSHALL
LOVE
BRYAN
Rush Springs
Marlow
Cruce
DUNCAN
Velma
Milroy
Fox
Loco
Addington
Healdton
Hewitt
WAURIKA
PAULS VALLEY
SULPHUR
Centrahoma
TISHOMINGO
ARDMORE
MADILL
MARIETTA
DURANT
LOWER CRETACEOUS
NORTHERN LIMIT
GULF COASTAL PLAIN
JUNE 1940
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FIG. 2

FIG. 2

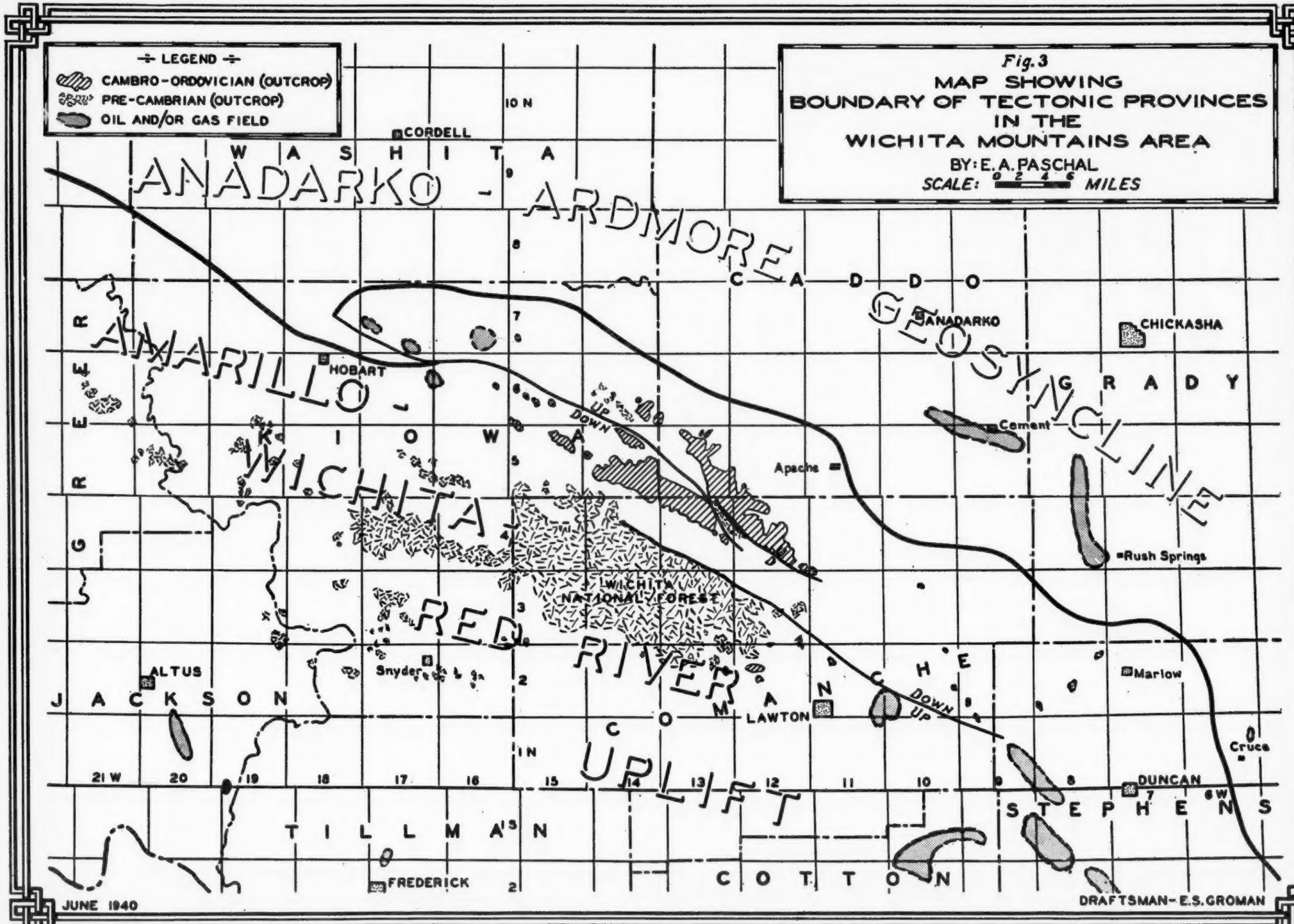


Fig. 3
MAP SHOWING
BOUNDARY OF TECTONIC PROVINCES
IN THE
WICHITA MOUNTAINS AREA
BY: E. A. PASCHAL
SCALE: 0 2 4 6 MILES
LEGEND
CAMBRO-ORDOVICIAN (OUTCROP)
PRE-CAMBRIAN (OUTCROP)
OIL AND/OR GAS FIELD
ANADARKO - ARDMORE GEOSYNCLINE
AMARILLO - WICHITA - RED RIVER UPLIFT
WASHITA
CADDO
GRADY
KIOWA
GREER
JACKSON
TILLMAN
COMANCHE
STEPHENS
COTTON
CORDELL
HOBART
ANADARKO
CHICKASHA
Cement
Apache
Rush Springs
WICHITA NATIONAL FOREST
ALTUS
Snyder
LAWTON
Marlow
Cruce
DUNCAN
FREDERICK
UP
DOWN
10 N
1N
21 W
6W
JUNE 1940
DRAFTSMAN-E.S.GROMAN

FIG. 3

syncline" as used by Dott.[13] The name "Amarillo-Wichita-Red River" has been derived by combining the Amarillo buried mountains, the Wichita and Criner mountains, and the Red River uplift into one province as was done by van der Gracht.[14] The term "geosyncline" has been used to convey the thought that the provinces so designated are long and narrow. A geological "basin" is defined by *Webster's New International Dictionary* (1935) as "an area in which the strata dip usually from all sides toward a center." Although this may be said to apply to the Permian strata in the Anadarko region it does not properly describe the structure of the Pennsylvanian and older beds in that region. It is also apparent that this definition does not properly describe the structure of the so-called "Admore basin" or the so-called "Arkansas Valley basin." On the other hand, a "geosyncline" is defined by Webster as "a great downward flexure of the earth's crust." Although the use made here may not be an exact application of the term "geosyncline" as defined, or as commonly applied in the literature, it is contended that it more nearly conveys the geological conditions prevailing than does the term "basin."

COMPARISON WITH CALIFORNIA PROVINCES

Except for the differences in the geologic age of the formations and the dates of the orogenies, the foregoing classification of provinces is here regarded as similar to that in southern California which has been made by Reed[15] in his classic work, *Geology of California*. In this and a later publication[16] he has divided southern California into six major tectonic provinces, three of which have rocks of the Franciscan series as their basement and three have a basement of granitic rocks. Regarding the nature of the Franciscan beds in the Coalinga district, Reed and Hollister[17] say:

> The Franciscan complex of this district includes igneous, sedimentary, and metamorphic rocks of all the kinds commonly found associated in other Franciscan areas. . . . The "blue band" . . . contains small fragments of sandstone, basalt, serpentine, radiolarian chert, glaucophane schist, and many others, all thoroughly kneaded together. Structurally, the Franciscan complex is like a mass of dough with a minor proportion of hard constituents interspaced. Except when it is overlain by a thick series of highly resistant beds, its instability permits the subjacent formations to become broken and bent very irregularly.

[13] Robert H. Dott, *op. cit.*, p. 596.

[14] Van der Gracht, *op. cit.*

[15] Ralph D. Reed, *Geology of California* (Amer. Assoc. Petrol. Geol., 1933).

[16] R. D. Reed and J. S. Hollister, "Structural Evolution of Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 12 (December, 1936), pp. 1533–1704.

[17] R. D. Reed and J. S. Hollister, *op. cit.*, pp. 1601 and 1603.

In discussing the nature of the areas underlain by the Franciscan beds, Reed[18] says:

> Extreme complexity of structure is almost a distinguishing feature of the Franciscan. Where it is overlain even by a thin cover of sediments, the latter also yield easily to deforming stresses. Folds of many types and sizes are therefore characteristic of areas underlain by the Franciscan. Faults are common, of which a great many are reverse, developed as a result of extreme folding. Examples of other varieties of faults are not rare. The distribution of the Franciscan series is for many reasons of very great importance to anyone who would understand the geologic history of California.

On the other hand, in speaking of the nature of areas underlain by granitic rocks, Reed[18] says:

> The Pliocene and Miocene beds resting upon the worn granite surface are nearly as flat as the Pennsylvanian beds of eastern Kansas. When an area underlain by granite at shallow depth has yielded to deformation, however, it has commonly done so either by faulting or warping. In a few areas thought to be exceptional, moderately strong folding is found in thin sediments so underlain.

It is here suggested that the Hunton-Tishomingo uplift and the Amarillo-Wichita-Red River uplift are, in a measure, comparable with the areas in California described by Reed which have a relatively thin sedimentary section and are underlain by granitic rocks. It is also suggested that the Arkansas Valley geosyncline and the Anadarko-Ardmore geosyncline are, in a measure, comparable with the areas in California described by Reed which have a relatively thick sedimentary section and are underlain by the Franciscan complex. The Ouachita Mountains province is composed of a thick sedimentary section somewhat like the areas underlain by the Franciscan complex, but since it appears to be a part of the Appalachian-Ouachita-Marathon "homogeneous mobile belt"[19] of thrusting which extends more than 2,000 miles across the North American continent,[20] no attempt is here made to compare it with any of the California provinces.

HUNTON-TISHOMINGO UPLIFT

The Hunton-Tishomingo uplift is considered as the southward extension of a positive sector of the North American plateau. It is characterized by a relatively thin section of comparatively flat post-

[18] Ralph D. Reed, *op. cit.*, p. 29.

[19] For an excellent study of "homogeneous" and "heterogeneous" mobile belts, the reader is referred to W. H. Bucher's *The Deformation of the Earth's Crust* (Princeton University Press, 1933). The last four provinces of southern Oklahoma lie within what Bucher calls a "heterogeneous" mobile belt.

[20] Philip B. King, "An Outline of the Structural Geology of the United States," *International Geological Congress Guidebook 28* (1933), p. 15 and Pl. I.

Ordovician beds. The greatest period of orogeny and that having the greatest bearing on oil accumulation occurred in early Pennsylvanian time. The local anticlinal features situated thereon, many of which have yielded prolific oil production, have been shown by McCoy[21] to be of the "vertical uplift" type.

AMARILLO-WICHITA-RED RIVER UPLIFT

The Amarillo-Wichita-Red River uplift is a southeast extension of a large positive feature which Ver Wiebe[22] shows as a part of the Ancestral Rockies. Although the post-Ordovician beds are relatively thin and comparatively flat, they are not of as uniform character and consistent thickness as beds of the same age in the Hunton-Tishomingo province. There have been two periods of major orogeny, one at or near the beginning of the Pennsylvanian (van der Gracht's Wichita phase)[23] and one at or near its close (van der Gracht's Arbuckle phase).[23] Many of the local structures have steep sides, usually faulted, and stand out abruptly above the surrounding area. Many of them appear to have been folded into anticlines in the first orogeny and uplifted as horsts in the second orogeny. Dott[24] shows that the southeast end of the Amarillo-Wichita-Red River uplift, as here shown, was thrust northward in the second orogeny, thereby overturning beds in the Hunton-Tishomingo uplift and compressing the Arbuckle and other anticlines within what is here called the Anadarko-Ardmore geosyncline. Van der Gracht[25] states that the Wichita Mountains seem to a very considerable extent to be faulted block mountains. It is here suggested that the faulted blocks observed at the surface extend beyond the mountains proper and are buried beneath the Permian redbeds.

ARKANSAS VALLEY GEOSYNCLINE

The Arkansas Valley geosyncline, as here discussed, extends in an easterly direction from Coal County, Oklahoma, at least as far as north-central Arkansas. It is here shown to range from 20 to 30 miles in width, bounded on the south by the Choctaw fault (Ouachita

[21] Alex. W. McCoy, "An Interpretation of Local Structural Development in Mid-Continent Areas Associated with Deposits of Petroleum," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 581–627.

[22] Walter A. Ver Wiebe, "Ancestral Rocky Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 765–88, especially Fig. 2, p. 774.

[23] Van der Gracht, *op. cit.*

[24] Robert H. Dott, *op. cit.*

[25] Van der Gracht, *op. cit.*

Mountain province) and on the northwest by the Continental plateau (Hunton-Tishomingo province). The beds at the surface are the coal measures of Pennsylvanian age. Due to its economic importance (coal and gas) much of the area has been studied in detail by geologists of the United States Geological Survey[26] whose reports contain excellent structural and stratigraphic data. The area has a comparatively thick section of incompetent beds and has been compressed into relatively steep elongate anticlines and synclines accompanied by faulting, overthrusting and a high carbon content of the coal. The line between the more steeply folded mobile geosyncline and the flatter immobile area on the north is surprisingly abrupt as is the line between the Franciscan and granitic provinces in southern California. As Hendricks[27] noted:

> This change in the structural pattern of the Arkansas coal field takes place along a narrow belt that extends almost due eastward from the Backbone anticline. . . . North of that zone the anticlines are gentle open folds, but south of it the anticlines are tightly folded as a result of compressive forces exerted from the south. In materials of comparatively uniform character a gradual transition from closely compressed anticlines at the south to slightly compressed anticlines at the north would be expected, and the abruptness of the change in structure just mentioned, suggests a pronounced change in the character of the strata. . . . North of the Backbone anticline the Atoka strata, as shown by deep well data, are underlain at a comparatively shallow depth by limestone and sandstone strata that are far more competent than the Atoka itself. Therefore, an abrupt southward increase in thickness of the Atoka formation would materially increase the thickness of incompetent surficial strata in that direction. Such a change seems adequate to explain the abrupt change in structural pattern in the central part of the Arkansas coal field.

ANADARKO-ARDMORE GEOSYNCLINE

The Anadarko-Ardmore geosyncline is here considered a deep, narrow immobile belt between two positive areas. It trends northwest and southeast and the part here outlined ranges from 18 to 27 miles in width. Due to insufficient information, no attempt has been made to show its full linear extent, but it is believed that when deep wells are drilled in search of oil, it will be found to extend much farther in both directions than is here indicated. In the vicinity of Ardmore, Pennsylvanian beds occur at the surface and have been described by Tomlinson[28] and others. Southeast of Ardmore the Pennsylvanian is

[26] "Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field," *U. S. Geol. Survey Bull. 874-A, 874-B, 874-C, and 874-D.* "Geology and Mineral Resources of the Western Part of the Arkansas Coal Field," *ibid., Bull. 874-E.*

[27] Thomas A. Hendricks, "Pennsylvanian Sedimentation in Arkansas Coal Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 11 (November, 1937), p. 1410.

[28] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (March, 1929).

overlain unconformably by Lower Cretaceous and on the northwest it is overlain unconformably by Permain redbeds. This covering of Lower Cretaceous and Permian has made detailed study of the surface of the Pennsylvanian similar to the study in the Arkansas Valley geosyncline impossible. However, the folding has been so great and extensive that it has been expressed in both the Lower Cretaceous and Permian beds despite the great unconformity separating them from the underlying, more steeply folded strata. Furthermore, the information derived from the drilling of wells for oil within the area has added materially to the knowledge concerning it. This geosyncline is considered to be similar to the Arkansas Valley geosyncline. It has a comparatively thick section of relatively incompetent beds of Mississippian and Pennsylvanian age which have been compressed into steep anticlines and synclines. Although the area was subjected to folding in the orogeny which occurred at or near the beginning of the Pennsylvanian (Wichita phase), the principal period of folding seems to have been at or near the close of the Pennsylvanian (Arbuckle phase). The conditions within the Ardmore sector have been described by van der Gracht[29] as follows.

> The folds at Velma, Graham, Caddo and Overbrook, and Madill are evidently situated within this basin. They are typical Arbuckle phase structures, consisting of steeply compressed Pennsylvanian, unconformably overlain by latest Pennsylvanian and Permian Pontotoc and Red-beds. . . . All the foredeep folds here discussed are true foothills folds in front of the principal Wichita chains, comparable with the open folds in front of the Ouachitas in the Coal basin of Oklahoma and the Arkansas Valley.

The Chickasha gas-field and Cement oil-field folds within the Anadarko sector of the province (Fig. 3) are here considered as having the same general character and history as the folds within the Ardmore sector.

NORTH BOUNDARY OF ANADARKO-ARDMORE GEOSYNCLINE

The north boundary line shown for the Anadarko-Ardmore geosyncline in the area of the Arbuckle Mountains is the line between the Arbuckle anticline and the Hunton-Tishomingo uplift as shown by Dott.[30] This line has been extended southeast in such a manner as to show the newly discovered Cumberland oil field of Marshall and Bryan counties within the Hunton-Tishomingo province and the structurally higher yet dry Aylesworth well in Sec. 14, T. 6 S., R 6 E., in the Anadarko-Ardmore geosyncline. It has been extended northwest beneath the Permian redbeds so that it lies approximately halfway

[29] Van der Gracht, *op. cit.*, p. 1015.

[30] Robert H. Dott, *op. cit.*

between a well in Sec. 15, T. 3 N., R. 2 W., which encountered competent beds (Viola limestone) below the unconformity at the Wichita phase of orogeny and a well in Sec. 14, T. 4 N., R. 5 W., which encountered incompetent beds (Springer shale) below the unconformity at the Wichita phase of orogeny. No attempt has been made to show the boundary farther northwest, but it is probable that it extends across western Oklahoma into the Texas and Oklahoma panhandles in a rather narrow belt conforming somewhat with the north boundary of the Bendian sea as indicated by Harlton[31] on his paleogeographic map. It appears that the boundary between the Hunton-Tishomingo and the Anadarko-Ardmore provinces is surprisingly abrupt. There is also a difference in the topography between the two provinces in the Arbuckle Mountain region as has been pointed out by Dott.[32]

> Locally, and topographically, the term "Arbuckle Mountains" refers only to the high range of hills between Davis and Ardmore, crossed by United States Highway 77, which is so designated on the Ardmore topographic sheet of the United States Geological Survey. These hills are the surface expression of a large anticline, the crest of which has been eroded into a broad slightly dissected plateau, from which rise two prominent peaks of pre-Cambrian porphyry, known as the "timbered hills" which attain an elevation of 700 feet above the valley of the Washita River and 1,400 feet above sea-level. The entire range is composed of a great sequence of rocks which ranges in age from pre-Cambrian to late Pennsylvanian. A similar succession of rocks occurs, in a much broader plateau, on the east, and though this area contains structural features of mountain proportions, and the surface is locally rugged, the elevations scarcely justify the name "mountains."

SOUTH BOUNDARY OF ANADARKO-ARDMORE GEOSYNCLINE

The boundary between the Anadarko-Ardmore geosyncline and Amarillo-Wichita-Red River uplift, as here shown, has been determined by application of both subsurface and surface data (Figs. 2 and 3). The Criner Mountains (Hills), and the Brock, Hewitt, Healdton, Loco, Woolsey, and Palacine oil fields have a comparatively thin section of post-Ordovician pre-Permain beds and are considered to be south of this boundary. On the other hand, wells drilled west of Fox and near Cruce have encountered steeply dipping black shale of Mississippian or Pennsylvanian age below the unconformity marking the Wichita phase of orogeny and show that they are north of this boundary line. The boundary between the areas is shown to bend and run almost due north through central Stephens County, thereby making the same

[31] Bruce H. Harlton, "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), Fig. 3, p. 1026.

[32] Robert H. Dott, *op. cit.*, p. 576.

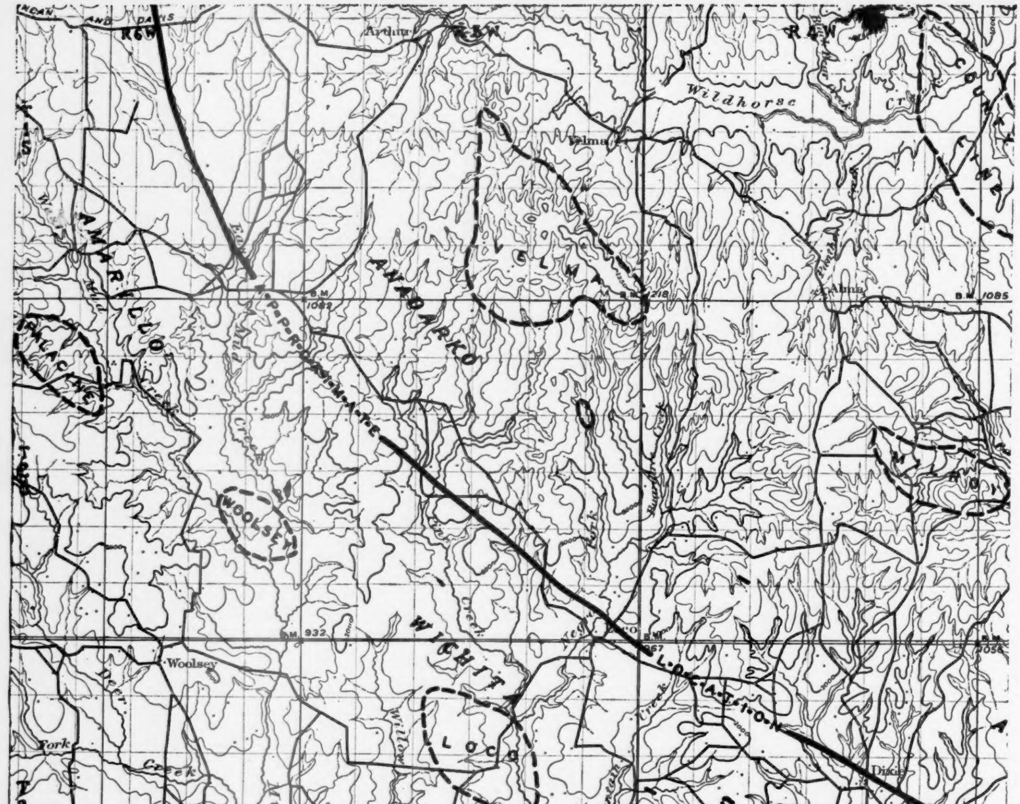
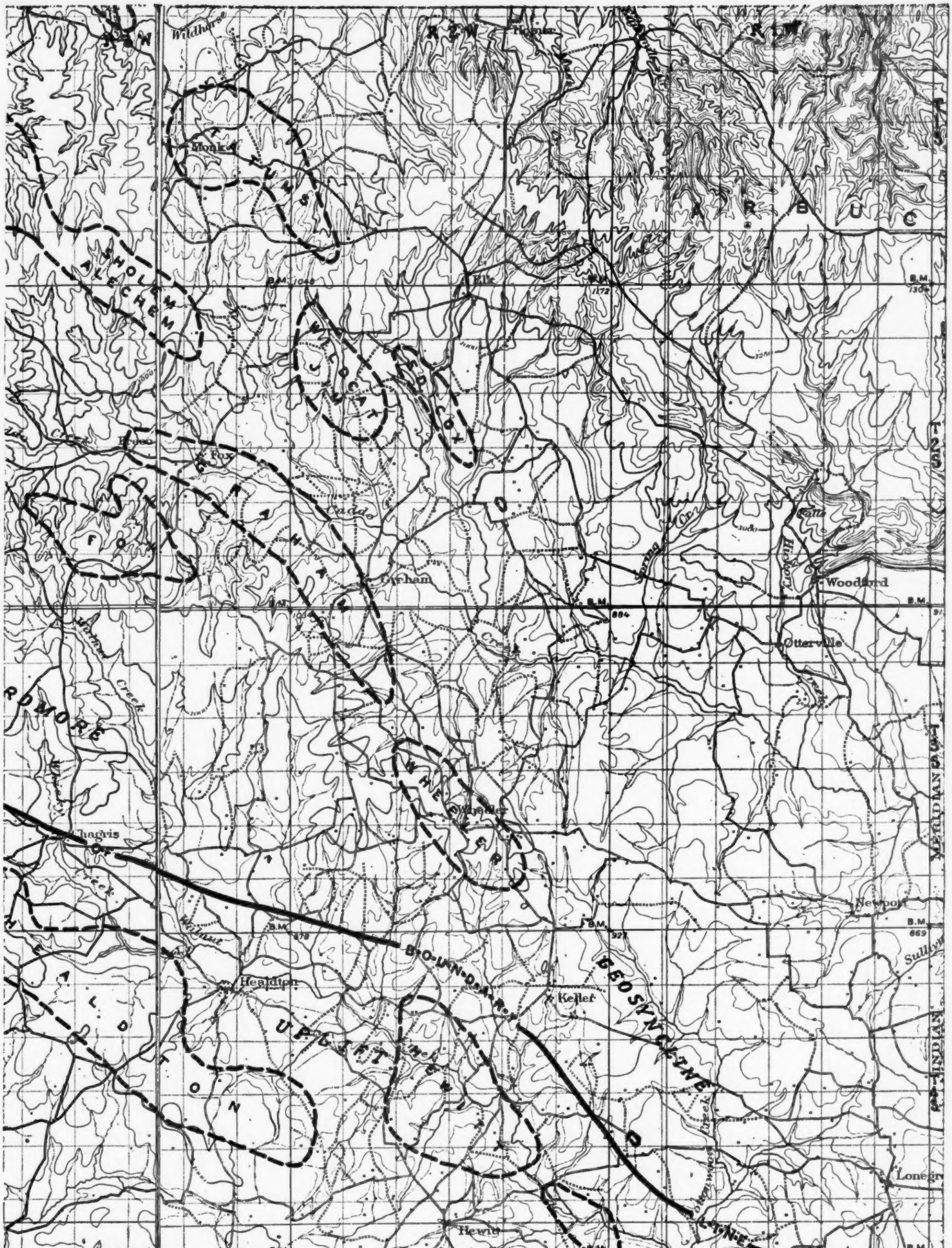
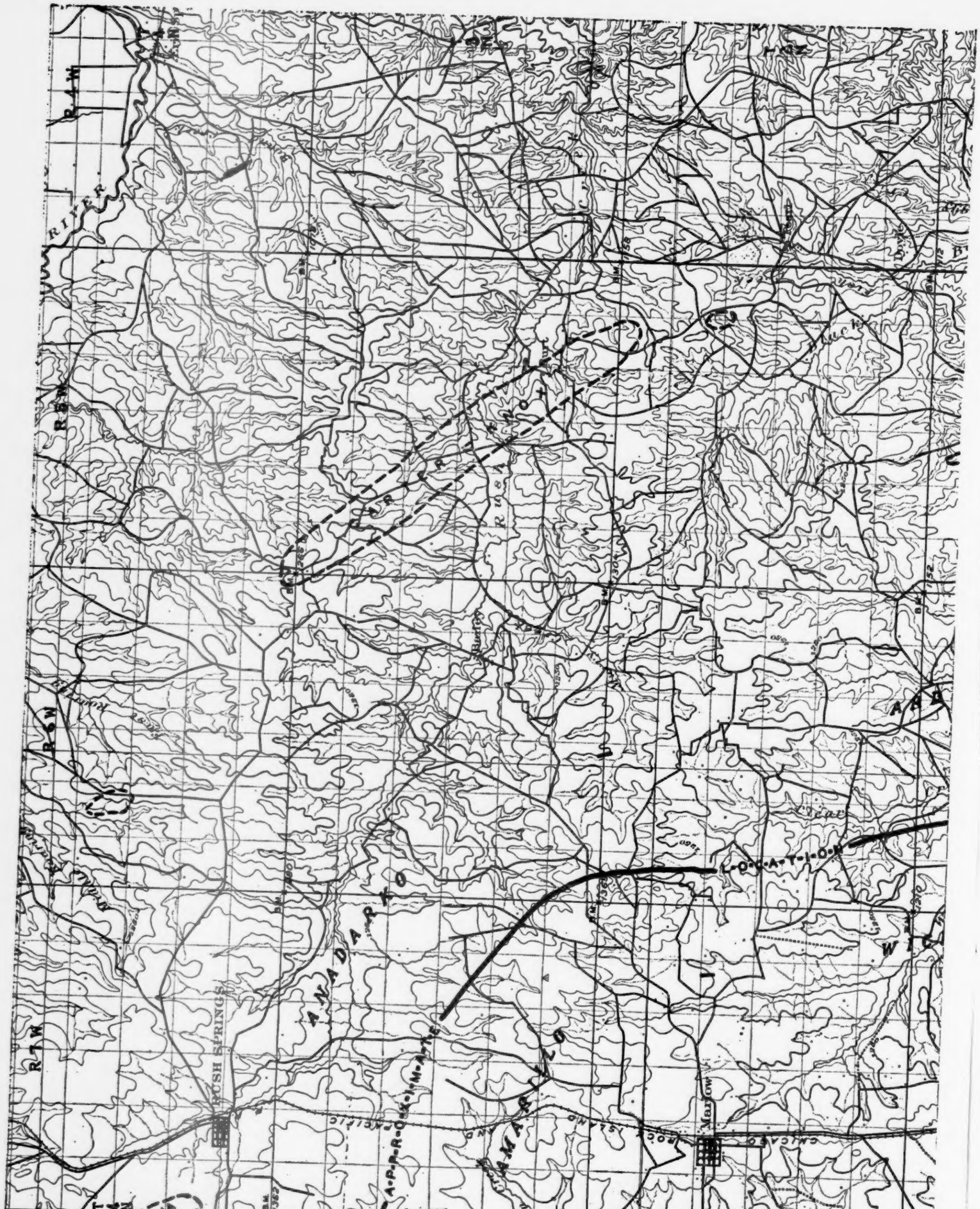


FIG. 4a.—United States Geological Survey topographic map of part of Ardmore and



Addington quadrangles, Oklahoma, with oil and gas fields outlined by heavy, dashed lines.


RIVER
R 4 W
R 5 W
R 6 W
R 7 W
T 5 N
RUSH SPRINGS
ANADARKO
AMARILLO
L-O-C-A-T-I-O-N
A-P-P-R-O-X-I-M-A-T-E
Marlow
CHICKASHA
PACIFIC
ROCK ISLAND
CHICAGO
OLD INDIAN TERRITORY - OKLAHOMA

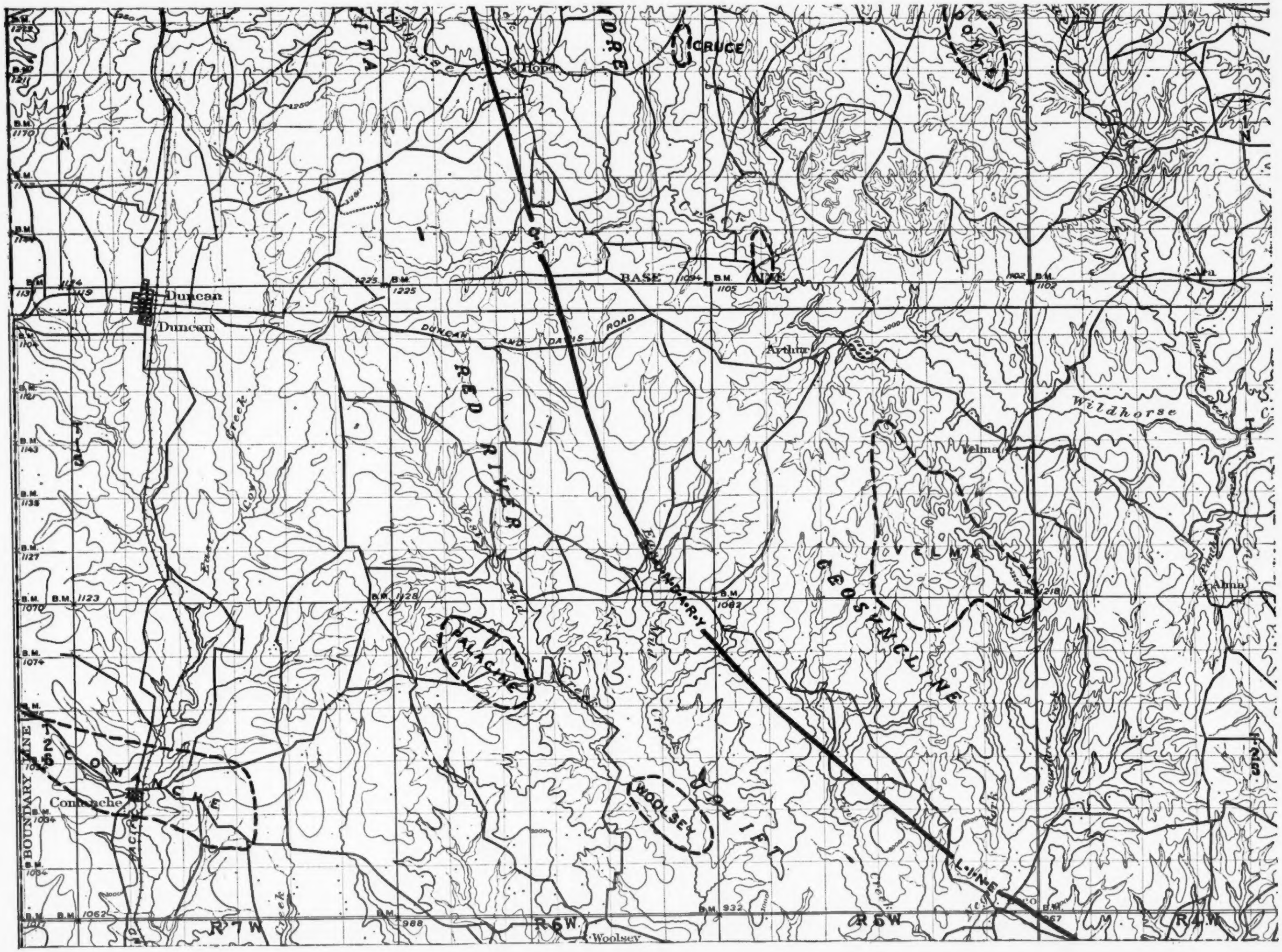


FIG. 4b.—United States Geological Survey topographic map of part of Addington and Rush Springs quadrangles, Oklahoma, with the oil and gas fields outlined by heavy, dashed lines.

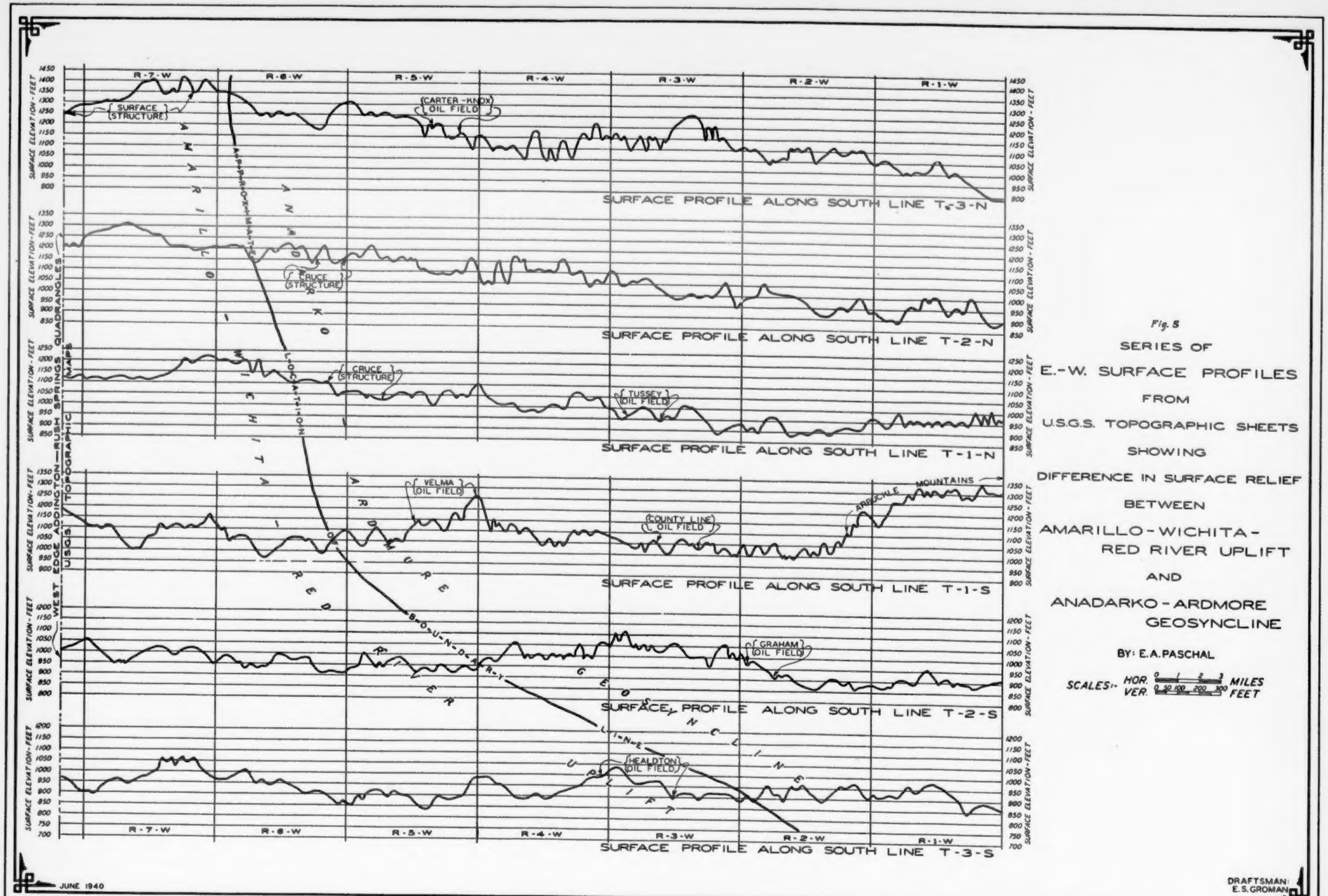


Fig. 5
SERIES OF
E.-W. SURFACE PROFILES
FROM
U.S.G.S. TOPOGRAPHIC SHEETS
SHOWING
DIFFERENCE IN SURFACE RELIEF
BETWEEN
AMARILLO-WICHITA-
RED RIVER UPLIFT
AND
ANADARKO-ARDMORE
GEOSYNCLINE
BY: E.A. PASCHAL
SCALES:- HOR. MILES
VER. FEET
SURFACE PROFILE ALONG SOUTH LINE T-3-N
SURFACE PROFILE ALONG SOUTH LINE T-2-N
SURFACE PROFILE ALONG SOUTH LINE T-1-N
SURFACE PROFILE ALONG SOUTH LINE T-1-S
SURFACE PROFILE ALONG SOUTH LINE T-2-S
SURFACE PROFILE ALONG SOUTH LINE T-3-S
R-7-W
R-6-W
R-5-W
R-4-W
R-3-W
R-2-W
R-1-W
SURFACE ELEVATION - FEET
SURFACE STRUCTURE
CARTER-KNOX OIL FIELD
CRUCE STRUCTURE
TUSSEY OIL FIELD
VELMA OIL FIELD
COUNTY LINE OIL FIELD
ARBUCKLE MOUNTAINS
GRAHAM OIL FIELD
HEALDTON OIL FIELD
AMARILLO - WICHITA - RED RIVER UPLIFT
ANADARKO - ARDMORE GEOSYNCLINE
APPROXIMATE LOCATION OF BOUNDARY LINE
WEST EDGE ADDINGTON—RUSH SPRINGS QUADRANGLES U.S.G.S. TOPOGRAPHIC MAPS
JUNE 1940
DRAFTSMAN: E.S. GROMAN

FIG. 5

curve made by the axis of the Milroy-Velma-Cruce structure and running parallel with it (Fig. 2). The boundary is then shown to turn westerly in southern Grady County and continue westerly along the north flank of the Wichita Mountains conforming approximately with the line where the northeast-tilted Permian redbeds show a decidedly abrupt increase in dip at the surface (Fig. 3). It is then shown to run northwesterly across the east part of the Texas Panhandle. One indentation is shown in the line in northern Kiowa County where drilling has verified surface indications and shown that the fault block on the north flank of the Wichita Mountains extends northwesterly beneath the redbeds. The newly discovered Hobart oil field, centering in Sec. 19, T. 7 N., R. 17 W., is here shown to be within the Amarillo-Wichita-Red River province.

DIFFERENCE IN TOPOGRAPHY

Having in mind the boundary between the two provinces, the writer has noticed in driving from Duncan to Ardmore that there appears to be a decided difference in the topography of the two areas. West of the boundary line the terrane is flat and rolling whereas east of the line it is more abrupt and broken. The thought then occurred that if this difference is as real as it appears it should show on the topographic sheets of the United States Geological Survey which cover the part of the area which has been mapped. The Ardmore, Pauls Valley, Addington, and Rush Springs quadrangles were joined into one sheet and the boundary placed thereon. Portions of this joint topographic map, which also has the oil and gas fields superimposed thereon, are here reproduced as Figure 4a and 4b. In addition a series of east-west profiles were made from the joint map, not at any selected place, but along the township lines. This series of profiles is here reproduced as Figure 5. One making a close study of Figures 4a, 4b, and 5 will be able to detect a decided difference in the topography of the two provinces. The writer has been told by a geologist who has flown over the area that this difference in topography can readily be observed from the air.

DIFFERENCE IN COLOR AND HARDNESS

This difference in topography can not be explained by a difference in outcropping formations. As can be seen from the geological map of Oklahoma the formations in Stephens County strike east and west and are the same on the east side of the line as on the west. It can, however, be explained by a difference in the hardness of the beds on either side of the boundary. Many of the local structures within the Anadarko-Ardmore geosyncline have local changes in the color and hard-

ness of the outcropping formations. This change is noticeable at Cement where the ordinarily soft red Rush Springs member of the Whitehorse sandstone of Permian age has changed to yellow, gray, and white, and in some places is so hard that it approaches quartzite. In the north end of the Chickasha gas field an upfolded inlier of the Chickasha-Duncan formation of Permian age, which is normally red and purple at this latitude, has been changed to gray and grayish yellow. This change in color and hardness is also noticeable in the Carter-Knox oil field in T. 3 N., R. 5 W., where the folding has brought the lower part of the Chickasha-Duncan formation to the surface. Also from about the middle of T. 1 N., R. 6 W., to about T. 2 N., R. 3 W., across the main part of the geosyncline, the basal Duncan sandstone along its east-west outcrop is predominantly gray to grayish yellow whereas in other areas it is predominantly red and purple. The color change in the underlying Hennessey shale across the geosyncline is even more marked than in the Duncan sandstone. The writer has traced this formation north and south across its outcrop in R. 6 W. and found the color line between the grays and grayish yellows on the east and the more reddish colors on the west to be very marked and to conform very closely with his previously drawn boundary between the Anadarko-Ardmore geosyncline and the Amarillo-Wichita-Red River uplift. It is also of interest to note that the Hennessey shale changes from predominantly gray to partly purple and then to predominantly red in a very few miles along its strike northerly across T. 2 N., R. 2 W., as it goes out of the Anadarko-Ardmore geosyncline onto the Hunton-Tishomingo uplift. It is believed that a detailed study of the formations below the Hennessey shale will show similar lateral changes in color of the beds as they pass out of the geosyncline to the more stable provinces on the northeast and southwest.

This difference in color is believed to be due to a difference in the cementing materials of the rocks. This difference in cementing material has caused a difference in the hardness of the rocks, the lighter-colored rocks being harder than those having the redder colors. The harder rocks have undergone more uneven erosion than the softer ones and the topography within the geosynclinal area, where the harder rocks crop out, is more broken and uneven than the topography of the more stable areas where the softer rocks crop out.

The change in color in the outcropping rocks in the Cement oil field has been explained by Reeves.[33]

[33] Frank Reeves, "Geology of the Cement Oil Field, Caddo County, Oklahoma," *U. S. Geol. Survey Bull. 726* (1921), pp. 55 and 56.

Apparently the alteration was induced by the folding of the rocks, and the agent that effected it was ground water. As the changes in color are due chiefly to addition of materials to the sandstone rather than subtraction, it is probable that the waters depositing these materials were ascending and not descending waters, for descending waters would have a leaching rather than a cementing effect on rocks lying near the surface, and besides there is no apparent reason why if a change of color were produced by descending waters in the anticlinal area a like change would not be produced in other areas, not anticlinal, which had a similar topographic relief, and there are in this region such areas in which no color change is present in the Whitehorse sandstone. On the other hand, ascending waters often effect near the surface a cementation of the rocks through which they pass. Such waters may be inferred to have been present as a result of the compression of the materials incident to the folding of the strata, the upward flow being confined to the area of greatest deformation—here the crest of the anticline—where fissures, joints and fault planes would furnish channels along which the waters could move with comparative ease. These waters were probably rich in carbonate solutions . . . and as these waters approached the surface a decrease of pressure and lowering of temperature would occur, with the result that carbonates would be deposited in the open-textured Whitehorse sandstone.

It is believed that the color changes other than those at Cement can likewise be explained by compression of the strata. It is also believed that the foregoing evidence indicates that the entire mobile belt here designated as the Anadarko-Ardmore geosyncline has been compressed or squeezed between the two positive areas since the deposition of the Permian redbeds. It also helps to explain the fact that the line between the more steeply folded mobile geosyncline and the flatter immobile uplift is surprisingly abrupt as are the lines between the southern California provinces.

DIFFERENT TYPES OF LOCAL STRUCTURES

It is here suggested that the local structures which are the controlling factors in the accumulation of oil and gas in the fields of the Arkansas Valley and Anadarko-Ardmore geosynclines were produced in a different manner from the local folds forming the oil and gas fields in the Hunton-Tishomingo and Amarillo-Wichita-Red River uplifts.

GEOSYNCLINES OF COMPRESSED TYPE

The local structures within the geosynclines are believed to have been formed primarily by lateral compression from a southerly direction. This lateral compression folded the sedimentary beds, especially those of Pennsylvanian and Mississippian age, into elongate anticlines and synclines which have their axes roughly perpendicular to the direction of the force forming them. It is further suggested that this compression or squeezing may have caused movements of under-

ground water and precipitation of siliceous and other cementing material within tl buried sands, the same as has been the case in the surface sands at ..ment and elsewhere, thereby reducing, if not destroying, their porosity. It is here suggested that this re-cementing process may explain the lack of porosity in the sands of the Simpson formation in the wells drilled on the Centrahoma anticline in the Arkansas Valley geosyncline. It may also explain the lack of porosity in the Simpson sands in the Sinclair-Prairie Oil Company's German well No. 1 north of the Wichita Mountains in Sec. 1, T. 6 N., R. 13 W., the Pure Oil Company's Noble well No. 1 on the Caddo anticline north of Ardmore in Sec. 35, T. 3 S., R. 1 E., and Johnson-Kemnitz' Godfrey well No. 1 on the Madill anticline in Sec. 14, T. 6 S., R. 6 E. (Aylesworth well), all within the Anadarko-Ardmore geosyncline. It is further suggested that the lack of porosity brought about by excessive compression of the strata may account for the relatively low recovery per acre in the Pennsylvanian sands of the Graham, Fox, and other Carter County oil fields within the geosynclinal area whereas the Healdton and Hewitt fields on the uplift on the south have had relatively high recoveries per acre from Pennsylvanian sands. It is further suggested that the shallow oil and gas found in the redbeds on the local structures, such as Wheeler, Graham, Milroy, Velma, and Chickasha, within the Anadarko-Ardmore geosyncline, was caused by this lateral compression which has in a sense "squeezed" the oil and gas out of the Pennsylvanian beds into the overlying strata.

Oil and gas accumulation in laterally compressed structures is not an uncommon type of occurrence as many of the fields of the world are in geosynclines which have, in general, had an orogenic history similar to these here described. This seems to be especially true of many of the most prolific fields of Europe and Asia which lie within the Mesozoic Tertiary belt of orogeny of the Eastern Hemisphere.

UPLIFTS OF VERTICAL UPLIFT TYPE

Powers[34] contended that the structures forming the Healdton, Hewitt, Brock (Crinerville), and many other fields were formed by the differential settlement of sediments over "buried hills." McCoy[35] made an extensive study of the subject in the Mid-Continent area and concluded that the structures forming Oklahoma City, Cushing, Seminole, Hewitt, and many other Mid-Continent fields are of the "local vertical uplift" type. In structures of this type the strata stand

[34] Sidney Powers, "Crinerville Oil Field, Carter County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 10 (October, 1927), p. 1082.

[35] Alex. W. McCoy, *op. cit.*, p. 627.

out structurally above the plane of the same formations in the surrounding area, a condition which he shows may be due "either to actual upward movement or to irregular downwarp." These folds are shown to have been uplifted periodically throughout the time which involves the entire sedimentary section encountered in wells drilled on them (with the main uplift near the beginning of the Pennsylvanian). As Dott[36] shows:

> This period of early Pennsylvanian uplift is probably the most important in the entire Mid-Continent region, for such important oil producing structures as Oklahoma City, Garber, Cushing, and El Dorado were built at this time. The same period saw the uplift of important areas in Kansas, and of the Bend arch in Texas, and the effects may have reached far beyond the Mid-Continent province. Of the same age, and more intimately related to the Hunton arch, are the folds which go to make up the Wichita-Red River mountains, and include the Criner Hills, Healdton Hills, Wichita Mountains, Amarillo buried mountains and the Red River uplift.

As has already been shown, the folds in the Amarillo-Wichita-Red River province have been subject to another great uplift at the close of the Pennsylvanian and stand out higher structurally above the surrounding area than do the structures of the Hunton-Tishomingo province. This second great uplift has resulted in greater closure on the local structures within the Pennsylvanian beds. This may partially account for the prolific Pennsylvanian production found in many of the fields on the Amarillo-Wichita-Red River uplift whereas many of the fields on the Hunton-Tishomingo uplift do not have prolific production from the Pennsylvanian.

UNDEVELOPED OIL PROSPECTS

On the Amarillo-Wichita-Red River uplift, very prolific oil and gas fields have been found on folds that are located on the margins of the uplift. The Brock, Hewitt, Healdton, and other fields in Oklahoma and the various fields in the Panhandle of Texas are along its north margin. The Burkburnett, K-M-A, Electra, and other fields in northern Texas are located on a line of folding along its south margin, which line of folding is known as the Red River "uplift." Due to the greater depth of the producing formations, the folds along the east end of the Red River part of the uplift in Clay and Montague counties, Texas, have not until recently been extensively explored. Due to the greater depth of producing formations the folds along the eastern extension of the fault block of the north flank of the Wichita Mountains, in eastern Comanche and northwestern Stephens counties,

[36] Robert H. Dott, *op. cit.*, p. 585.

Oklahoma, along the north margin of the Amarillo-Wichita part of the uplift (Fig. 3), have not been extensively prospected. However, a few wells in this region have had excellent showings of oil and have yielded evidence of local structure.

The possibilities of oil or gas production from the Ordovician beds in the southern part of Oklahoma have by no means been fully exhausted as Tomlinson[37] shows in the following statement.

> The date of folding of a given mountainous anticline in this region is of vital importance to the oil producer who is testing its commercial possibilities. In the folds formed first in early Pennsylvanian time, the drill passes through a relatively thin section of upper Pennsylvanian beds into exceedingly steeply folded pre-Pennsylvanian strata lying unconformably beneath them.

Since the local structures on the Hunton-Tishomingo and the Amarillo-Wichita-Red River uplifts were first formed in early Pennsylvanian time and since they are regarded as "uplifted" and not "compressed" folds, they are believed to offer better opportunities for Ordovician production than do the local structures within the Arkansas Valley and Anadarko-Ardmore geosynclines. Although the Ordovician beds are known to lie at depths of 10,000 feet or more, in the most promising parts of the undeveloped area, it is believed that fields producing therefrom will prove profitable especially where thick bodies of "Wilcox" sand are found. Decreasing costs of deep drilling and more efficient well spacing and producing methods will contribute much to make such fields profitable.

[37] C. W. Tomlinson, *op. cit.*, p. 50.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 1 (JANUARY, 1941), PP. 23-72, 2 FIGS.

TRAVERSE OF UPPER DES MOINES AND LOWER MISSOURI SERIES FROM JACKSON COUNTY, MISSOURI, TO APPANOOSE COUNTY, IOWA[1]

L. M. CLINE[2]
Ames, Iowa

ABSTRACT

This paper summarizes the stratigraphic results of a traverse of the Pennsylvanian upper Des Moines and lower Missouri series made along the strike from near Kansas City, Missouri, to Appanoose County, Iowa, an outcrop distance of 180 or 200 miles. The main objective of the traverse was the correlation of the heretofore unknown Iowa section of the Des Moines series with that of west-central Missouri. Standard names, long accepted in Missouri and Kansas, have been applied to the Iowa formations where this is possible. In addition, considerable new information concerning the stratigraphy of the Pennsylvanian of north-central Missouri is presented. Stratigraphic conclusions are presented in the form of eleven columnar sections, each composite for a selected area. The sections are drawn to scale and show regional variations in lithology and thickness.

INTRODUCTION

In order to correlate the Des Moines formations of the Pennsylvanian system in southern Iowa and northern Missouri the writer made a traverse along the strike of the upper Des Moines and lower Missouri series from the vicinity of Kansas City, Missouri, to northern Appanoose County, Iowa, an outcrop distance of 180 or 200 miles. This traverse was made primarily to become familiar with the stratigraphic section worked out by the Missouri Geological Survey. To this end most of the described exposures along the traverse were examined, important ones were redescribed, and this work supplemented with studies of previously undescribed exposures.

These studies have in general substantiated previous work of the Missouri Survey but it has been possible to correlate, for the first time, some of the higher Des Moines beds in the Iowa and Missouri areas. Stratigraphic conclusions are presented in the form of eleven generalized columnar sections, with a description and discussion of each section. The sections are plotted to scale and show regional variations in lithology and thickness. Correlations between Appanoose County, Iowa (Section XI), and Lafayette County, Missouri (Section II), are fairly certain, but we are not satisfied with the tie-in between Sections I and II. It is hoped that the publication of this paper will stimulate further work in the Des Moines series from the Kansas City

[1] Published with the permission of the director of the Iowa Geological Survey. Manuscript received, August 15, 1940.

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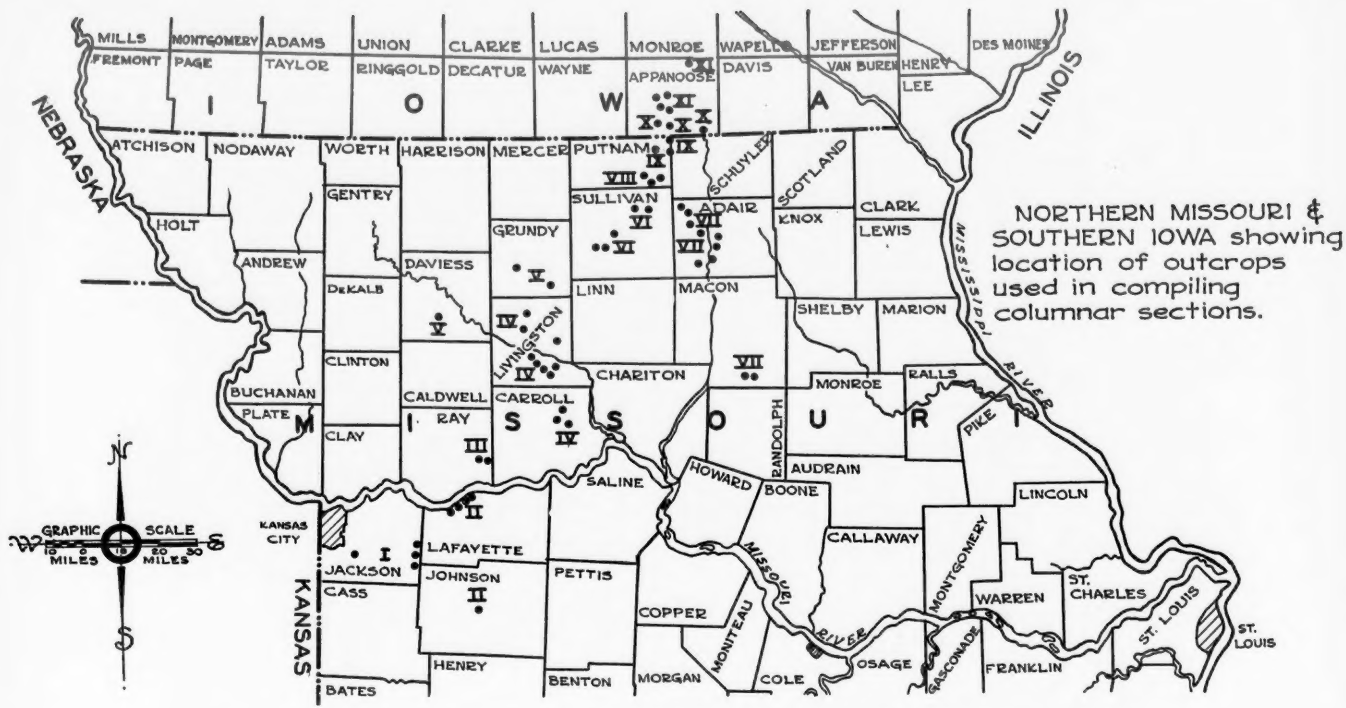


FIG. 1.—Northern Missouri and southern Iowa showing location of outcrops used in compiling columnar sections.

area south and west into southeastern Kansas. Special attention should be given to the careful tracing of the Pawnee and Fort Scott limestones from their type sections in southeastern Kansas across southwestern Missouri as far north as the Missouri River, so as to make known the exact status of the Blackjack Creek limestone ("lower Fort Scott" of Missouri reports), Houx limestone ("Rhomboidal limestone"), Higginsville limestone ("upper Fort Scott limestone"), Myrick Station limestone ("Lexington caprock"), Worland limestone, and the Exline limestone.

ACKNOWLEDGMENTS

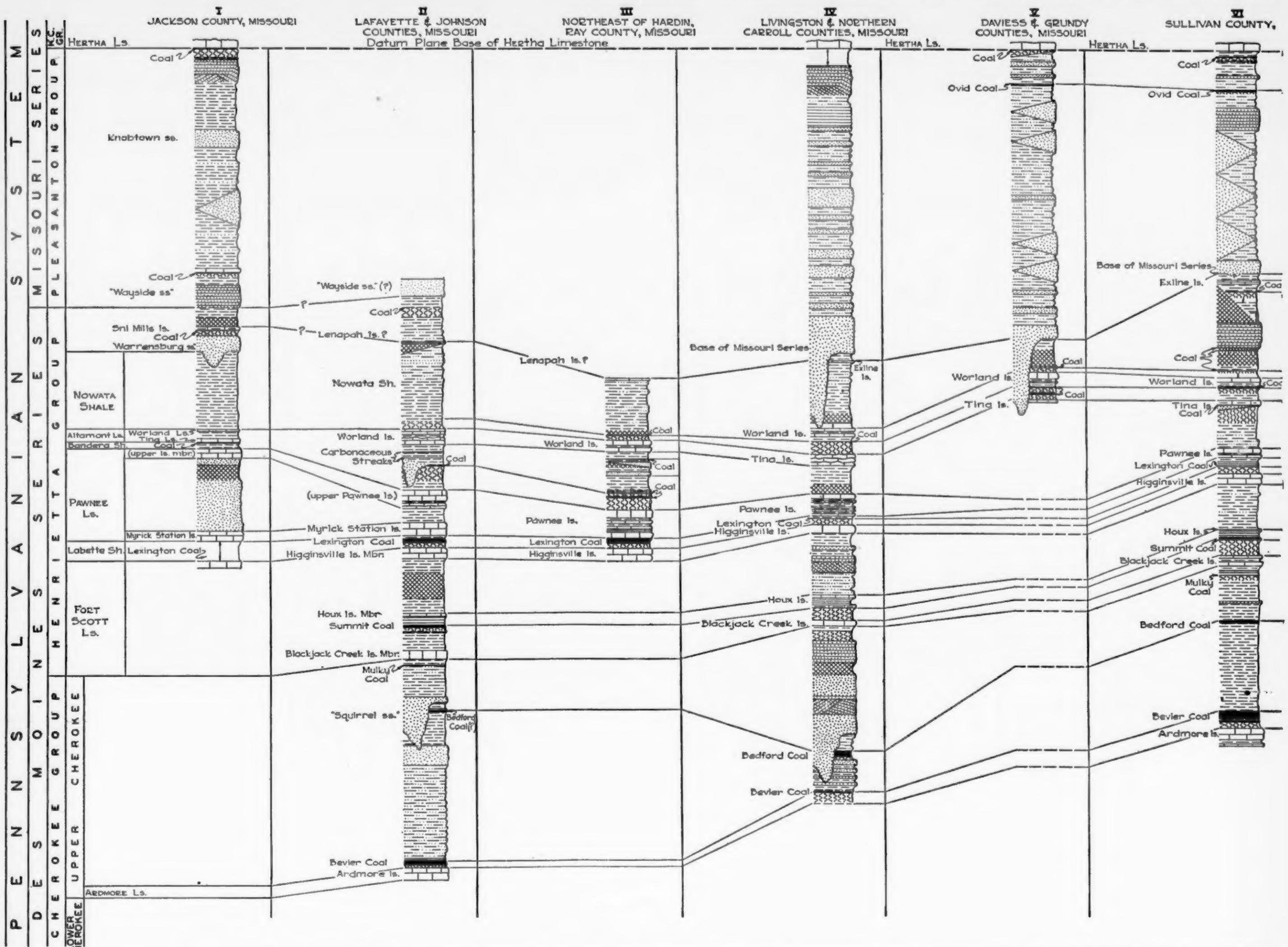
Detailed stratigraphic studies of the Pennsylvanian of Iowa were begun by the Iowa Geological Survey in 1933 under the direction of A. C. Tester of the State University of Iowa. In the early part of this work D. G. Stookey and M. L. Thompson were associated with Tester in a study of the lower Des Moines beds in southeastern Iowa. Stookey completed and submitted to the Survey for publication a paper titled, "Stratigraphy of the Des Moines Series of Southeastern Iowa." Later his studies were extended to some of the higher beds of the series and he worked as far northwest along the outcrop as Warren County.

Whereas the writer assumes full responsibility for the correlations made in this paper, he gratefully acknowledges the guidance of Dr. Tester throughout the early part of the work. Measurements and descriptions of the lower part of Section X and most of Section XI are largely from Stookey's manuscript but the writer has thoroughly checked every foot of each section.

It is a pleasure to acknowledge the aid given by Frank C. Greene of the Missouri Geological Survey, who helped the writer become acquainted with the stratigraphy of the Kansas City area, where the traverse was begun; and with Raymond C. Moore and J. M. Jewett of the Kansas Survey he checked some of the writer's field work when the traverse was completed and he correctly correlated some of the beds that had offered difficulty.

The encouragement and aid given by A. C. Trowbridge, director of the Iowa Survey, and the friendly advice and criticism of Dr. Moore are gratefully acknowledged. Special thanks are due Dr. Moore for suggestions pertaining to problems in nomenclature and classification. Mr. Jewett has kindly furnished information, in part unpublished, regarding the southeastern Kansas section.

CROSS SECTION OF THE UPPER DES MOINES AND LOWER MISSOURI SERIES FROM



JACKSON COUNTY, MISSOURI, TO APPANOOSE COUNTY, IOWA

MISSOURI

VII ADAIR COUNTY, MISSOURI

VIII PUTNAM COUNTY, MISSOURI T. 65 N., R. 18 W.

IX PUTNAM COUNTY, MISSOURI T. 67 N., R. 18 W.

X APPANOOSE COUNTY, IOWA T. 67 N.

XI CENTRAL & NORTHERN APPANOOSE COUNTY, IOWA

Hertha Ls.

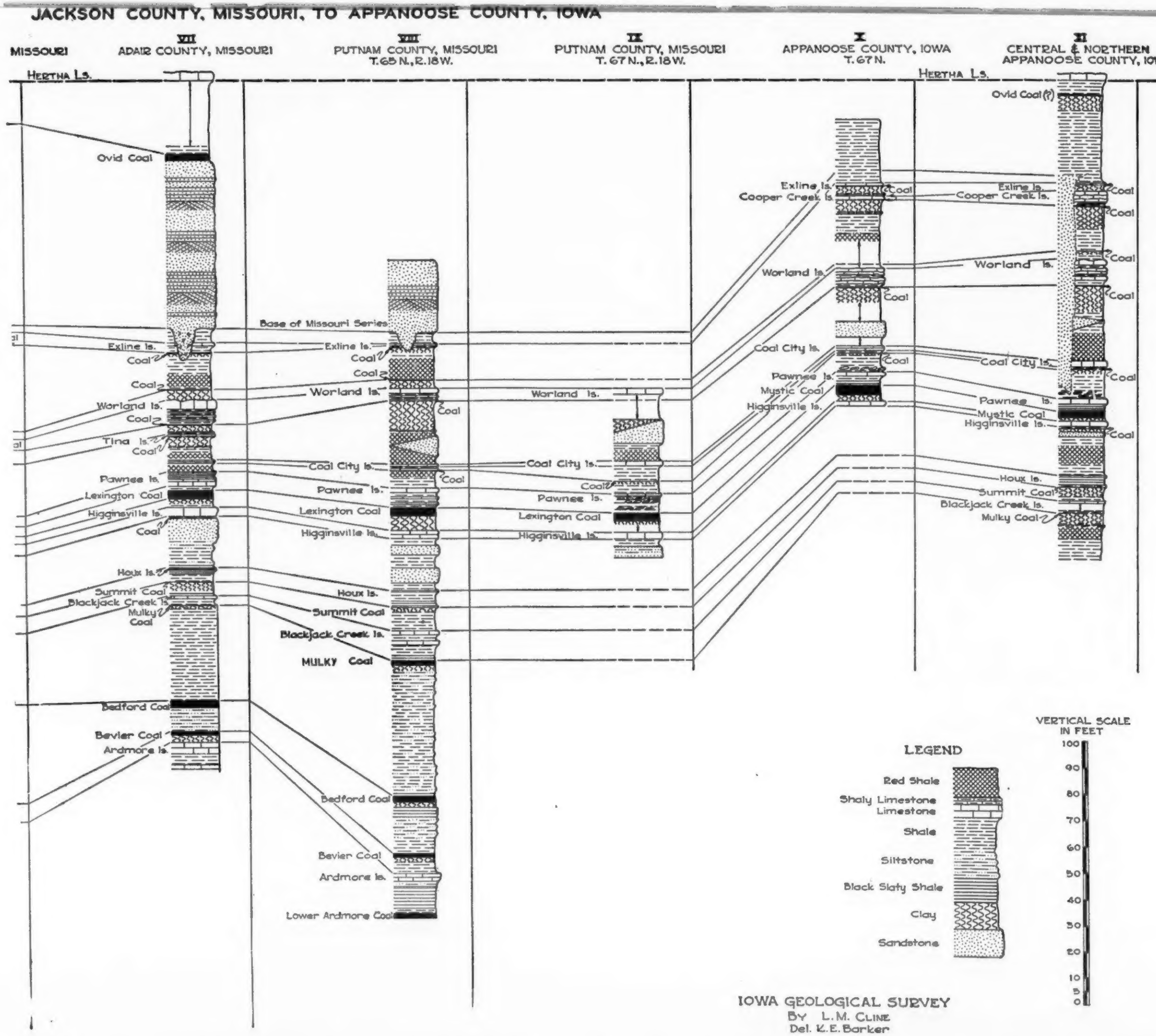


FIG. 2.—Cross section of upper Des Moines and lower Missouri series from Jackson County, Missouri, to Appanoose County, Iowa.

SECTION I

Generalized for Jackson County, Missouri

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
31. Hertha limestone		
Pleasanton group		
30. Shale; green-gray		6
29. Shale; black and slaty; coal horizon		½
28. Clay; light to dark gray, or green mottled with maroon, blocky; local development of impure nodular limestone in lower part	4	
27. Sandstone, green-gray, weathers yellow; fine- to medium-grained, friable, micaceous; thin-bedded to massive, in many places cross-bedded; replaced laterally by shale and siltstone which merges with zone 26 below	8	6
26. Shale and siltstone; gray, weathers drab; thin-bedded	21	6
25. Sandstone (Knobtown); top flat, upper part calcareous and fossiliferous; more resistant to weathering than adjacent beds	7	
24. Shale; lithology variable; argillaceous, arenaceous, or locally containing thick sandstone; 40–60 feet	50	
23. Limestone; dark, shaly, fossiliferous; 0–3 feet	1	6
22. Carbonaceous streak		
21. Clay and shale; limestone nodules in basal part of clay	5	
20. Sandstone; gray, weathering drab; thin, even beds; 6–12 feet ("Wayside sand" of drillers)	9	
Des Moines series		
Henrietta group		
19. Shale; blue-gray to green-gray, lower part locally maroon	8	
18. Limestone (top of Sni Mills); gray, argillaceous, carbonaceous, and fossiliferous; 3–5 inches		4
17. Shale; dark gray		½
16. Limestone; dark blue-gray, fine-grained, fossiliferous (zones 16–18 constitute Sni Mills limestone)		3
15. Sandstone; green; upper surface contains fusulinids that may be of Des Moines age; 1½–3 inches		2
14. Clay; green and red mottled	2	3
13. Sandstone; gray, hard, calcareous, thin-bedded to massive; thickness extremely variable; marginal or sheet phase of channel sandstone that according to Missouri Survey forms base of Missouri series in this area ("Warrensburg")	6	
12. Shale; gray, greenish, or red; present where overlying sandstone is thin (Bandera)	33	
11. Limestone (Worland); gray, fossiliferous		8½
10. Shale; gray, calcareous, highly fossiliferous; contains fusulinids, *Mesolobus*, and large crinoid stems	3	
9. Limestone (Tina); gray, weathers deep buff, very fossiliferous	1	
8. Shale; dark, carbonaceous streak at top	2	
7. Limestone (upper Pawnee); light gray, dense, upper part brecciated; heavy irregular beds with nodular masses filling space between *Chaetetes* heads	4	2
6. Sandstone	3	
5. Shale; red and green	6	
4. Sandstone; base not exposed	21	
3. Limestone (Myrick Station); gray, weathers brown; contains fusulinids; *Chaetetes* in thin sheets	4	
2. Covered interval; some shale exposed	8	
1. Limestone; exposed in bed of creek (top of Fort Scott)		

Discussion of Section I

Section I is primarily based on outcrops in eastern Jackson County. This area was studied by the Tenth Annual Field Conference

of the Kansas Geological Society and in the conference guidebook there are generalized sections showing the stratigraphic succession from the Hertha limestone to the top of the Fort Scott formation; a discussion by F. C. Greene (1936, pp. 17–22) is included. Measurements are principally from the published works of Greene and others but the descriptions have been modified and the Des Moines-Missouri boundary placed at a slightly higher position.

Descriptions of zones 25 to 31 are chiefly from exposures near Knobtown, in the center of the N. ½, SE. ¼ of Sec. 27, T. 48 N., R. 32 W., in a cutbank on the north side of road 8S. Zones 15–19 were measured in a south-side cutbank of a creek, a short distance west of the highway bridge and in the NE. ¼, SE. ¼ of Sec. 5, T. 47 N., R. 29 W., a locality about 2 miles south of Sni Mills. The measurements listed for the remaining zones are after Greene and, except for some minor changes, the descriptions are also after Greene.

DES MOINES SERIES

HENRIETTA GROUP

Higginsville limestone.—The base of Section I is the "bottom-rock" (Higginsville limestone) of the Lexington coal and is correlative with the top of the Fort Scott limestone.

Altamont limestone.—Zones 9 and 11, named the lower and upper Worland limestones by Greene in 1933 (pp. 14, 18) have in the older reports been included in the Pawnee limestone. In a recent field conference in which the writer participated, Moore, Jewett, and Greene traced the lower and upper Worland limestones from the Missouri River across southwestern Missouri and into southeastern Kansas and showed them to be equivalent to the lower and upper Altamont limestones, respectively. In Carroll County, Missouri, the two limestones are separated by a coal smut and several feet of underclay.

For the lower limestone member of the Altamont the writer proposes the name Tina. Typical exposures may be seen about 2 miles southeast of Tina, Carroll County, Missouri, in ravines in the west-central part of Sec. 7, T. 54 N., R. 22 W., where, together with the upper member of the Altamont, it is quarried on both sides of the east-west road. Moore and Jewett (personal communication, June 2, 1940) have suggested that it would be appropriate to retain the name Worland for the upper member of the Altamont. They will select a type section near the town of Worland for that member.

MISSOURI SERIES

PLEASANTON GROUP

The recognition of an important unconformity within the Pleasanton group (of earlier Missouri terminology) necessitated a redefinition of the Henrietta and Pleasanton groups. Moore (1932, p. 89; 1936a, pp. 57, 58) has suggested that the Kansas terms Marmaton and Bourbon could appropriately be used in Missouri, but in a recent publication of the Missouri Geological Survey (McQueen and Greene, 1938, pp. 20, 21) the Henrietta and Pleasanton groups were merely redefined so that their common boundary coincides with the Missouri-Des Moines series contact as defined by Moore.

The Hertha, an easily identifiable limestone in the lower part of the Missouri series, has been selected as the datum plane for the cross section.

Lower Pleasanton sandstones.—The "Wayside sand" (zone 20) of drillers is supposed to be the same as the Wayside sand of Wayside, Kansas, which is not the equivalent of the Wayside sandstone of Illinois of Pottsville age. The base of the Missouri series is tentatively drawn at the base of the "Wayside sand."

The correlation of the lower Pleasanton sandstones of Missouri has been a subject of much controversy. It is generally agreed that the faunal break between the Des Moines and Missouri series is caused by an important unconformity in the lower part of the Pleasanton (as it was formerly defined) and it appeared that the problem was settled with the correlation of a widespread channel sandstone in the subsurface of the Kansas City area with the Warrensburg channel sandstone of counties on the east and southeast. The Warrensburg had earlier been correlated with channel sandstones in the Pleasanton of north-central Missouri, which in turn were correlated with the Chariton conglomerate of Iowa. The question has recently been raised as to which of two recognized unconformities in the lower Pleasanton of western Missouri is the greater; one of these unconformities is at the base of a sandstone generally identified as Warrensburg (zone 13 of Section I), and the other is above the "Warrensburg" at the contact of the Sni Mills limestone. This problem is of such stratigraphic importance that its oft-reviewed history is briefly discussed in the following paragraphs.

McCourt, Albertson, and Bennett (1917, pp. 33, 34) give an average thickness of 163 feet for the Pleasanton in Jackson County, noting that,

> at 29 to 50 feet above the base . . . there has been found in each of 21 wells, a bed of red clay or shale, 2 to 12 feet thick, . . . at an average distance of 40 feet above the Pawnee limestone. It has been found at many widely separated places in and near Jackson County and is evidently fairly persistent.

Greene (1933, pp. 18, 19) correlated outcropping red shales and sandstones in the lower Pleasanton of western Missouri with the Warrensburg of Johnson County and with several buried channels in Jackson and surrounding counties. A sandstone between two layers of red shale was identified as the marginal phase of the Warrensburg channel sandstone which he and Hinds (Hinds and Greene, 1915, pp. 91–106) had earlier traced for 50 miles northward from Henry County through central Johnson and Lafayette counties. Bartle (1933, pp. 16, 17, 18, 25, 26) recognized an unconformity at the base of a shoestring sandstone in the lower Pleasanton of the Blue Springs gas field in Jackson County. This sandstone, which was shown in a figure on Plate 2 as cutting through the Henrietta and resting on upper Cherokee, was correlated with the Warrensburg.

In the section which Greene and Clair (Greene, 1936, p. 20, Fig. 8) measured for the Tenth Annual Field Conference of the Kansas Geological Society, the base of the Missouri is questionably drawn below the Sni Mills limestone. An underlying sandstone was stated to be the marginal or sheet phase of the Warrensburg. A thin green sandstone just below the Sni Mills was said to contain fusulinids of questionable Des Moines age. The following discussion by Greene (1936, pp. 18, 19) of the Sni Mills section is quoted from the conference guidebook:

> The Bourbon group of beds, which may be seen here, has been imperfectly understood and interpreted in most of the publications on Missouri, and at present is still a problem. The base of the group, which is also the base of the Bourbon formation, is, by definition, at the disconformity separating the Missouri and Des Moines. There is evidence of two disconformities, however, one above the Warrensburg sandstone, and, of course, one below it where it replaces 100 feet or more of the beds normally present. I defer to the judgment of others on the question as to which is the important unconformity. . . . The supposed position of the upper disconformity . . . is located either at the upper or lower contact of the Sni Mills limestone, this conclusion being based on observation of the lateral irregularity of the beds above and below the contact in other areas. In the zone between the supposed disconformities is the Warrensburg sandstone with red and green shale above and below the sandstone in its marginal phase.

In the generalized section given on page 19 of the guidebook, presumably the work of Moore and Greene, the Warrensburg is included in the Des Moines series.

McQueen and Greene (1938, pp. 24–26) believe the most practical dividing line between the Des Moines and the Missouri series is the top of "the highest limestone below the Warrensburg zone," recognizing that this would not be the same stratigraphic plane in all cases. They state that well logs show the Warrensburg to lie below a wide-

spread bed of black slaty shale, which is believed to represent the Dawson coal of Oklahoma. A thin bed of calcareous fossiliferous shale above the "Wayside sandstone" was correlated with the *Trepospira* zone (the Exline limestone of this report) of north-central Missouri, and the lower Pleasanton channel sandstones of the latter area (and the Chariton conglomerate of Iowa) were tentatively correlated with the Knobtown sandstone.

In a publication issued early in 1939 Grohskopf, Hinchey, and Greene (p. 22) state,

> The relations of the different beds of the Pleasanton to each other are not well understood, but a few tentative suggestions can be made. The sandstone which forms the bulk of the Pleasanton in northeastern Missouri, probably has no relation to the Warrensburg, but is more likely associated with the Knobtown member of the Kansas City area.

The results of this traverse indicate that the most widespread channel sandstone of the Pleasanton (of former reports) of northern Missouri, and likewise the most pronounced unconformity, lies a short distance above the Exline limestone, rather than below it, and apparently this represents the most important stratigraphic break between the Worland and Hertha limestones. The writer is of the opinion that when the position of the Des Moines-Missouri unconformity in west-central Missouri is definitely fixed in relation to the thin limestone and other persistent units in the lower Pleasanton, and these units have in turn been correlated with the north-central Missouri section, the greatest unconformity will be found to be above the Exline limestone equivalent. Accordingly, the base of the Missouri series is tentatively placed at the base of the "Wayside sandstone" of the Kansas City area.

Upper Pleasanton.—The Knobtown sandstone (zone 25) is said by Greene (1938, oral communication) to be a good key bed in the highly variable clastic interval of the upper Pleasanton in the Kansas City area.

The persistent black shale of zone 29 has been termed Ovid in several publications (Greene, 1936, pp. 19, 20) but it may not be the Ovid of the type locality. The Ovid, where present in the traverse, occurs some 15 or 20 feet lower and in Sullivan and Adair counties it is thick enough to be mined.

The local development of nodular limestone at the base of zone 28 may be the equivalent of the "Critzer limestone" of Jewett (1932, p. 99; 1933, pp. 134–36) which Moore and Greene (Moore, 1936b, p. 75) believed to be equivalent to the "Fragmental limestone" (Cooper Creek) of Iowa. Moore states:

We have seen this rock above the Ovid in northern Missouri and southern Iowa. The "Critzer" is apparently a "super" limestone, representing the receding algal, molluscan phase of the sedimentation cycle that includes the Ovid coal, and it is probable that somewhere along the strike other typical members of the cyclothem will be observed.

West of Milan, Sullivan County, impure nodular limestone of the type so commonly found in the lower part of underclays occurs in the underclay which is found below the black shale just beneath the Hertha. It is shown in another part of this paper that this nodular limestone is not equivalent to the "Fragmental" of Iowa.

SECTION II

LAFAYETTE AND JOHNSON COUNTIES, MISSOURI

Top	*Feet*	*Inches*
Missouri series		
Pleasanton group		
57. Sandstone; yellowish gray; brown, limonitic areas on fresh surface; friable, medium-grained; massive to cross-bedded; 6–8 feet; full thickness probably not exposed ("Wayside")	7	
Des Moines series		
Henrietta group		
56. Shale; green-gray, weathering drab; silty	4	6
55. Shale; soft, dark blue-gray to black with some green mottling		6
54. Clay; red and green mottled, weathers to red soil	3	9
53. Shale and siltstone; thin discontinuous beds interrupted by lenses of fine-grained sandstone, the whole weathering drab	10	
52. Limestone (Lenapah?); persistent bed of coarsely crystalline crinoidal gray limestone with rusty iron-stained areas		7
51. Shale and siltstone (Nowata); thin-bedded but with blocky fracture; thin lenticular bodies of fine-grained green-gray sandstone in upper half; lower half largely composed of blue-gray to green-gray well bedded shale; lower few feet platy; locally the upper few feet contain red and green mottled shale and siltstone	32	6
50. Green clay	3	
49. Limestone (top of Worland); two or three beds of massive, light gray, fine-grained, sub-lithographic fossiliferous limestone, weathering deep buff to brown; a few rather large fusulinids	2	
48. Shale and nodular limestone; lithology variable; highly fossiliferous with *Mesolobus*, other chonetids, and fusulinids	1	3
47. Limestone; two beds of massive, jointed limestone, lithologically much like zone 49; island-like masses of *Chaetetes* rise above main ledge of limestone to give irregular upper surface; fossiliferous; *Chaetetes*, large fusulinids, *Composita*, *Neospirifer*, *Chonetes*, and Bryozoa abundant; 2½–3 feet (zones 47–49 are Worland limestone)	2	9
46. Shale; green-gray, thin-bedded, soft, calcareous, fossiliferous; especially abundant and persistent are large crinoid stems, a small species of *Mesolobus*, and a large species of *Ambocoelia*	2	8
45. Dark shale; gray to black with zone of ash-gray, almond-shaped phosphatic concretions		3
44. Shale; green, fossiliferous; fauna like zone 46	2	6
43. Carbonaceous shale; varies from 3 inches to mere film		1½
42. Shale; green, silty, micaceous, thin-bedded, non-fossiliferous; laterally replaced by sandstone which may extend downward to cut out lower beds	3	
41. Coal; varies from 2 to 10 inches where present but locally cut out by sandstone of zone 42 (Mulberry)		5

	Feet	Inches
40. Interval composed largely of green clay but at one locality undetermined thickness of shale rests on underlying Pawnee limestone; locally sandstone of zone 42 extends downward to cut out part of green clay	10	
39. Limestone (top of Pawnee); gray, weathers yellow, fine-grained, sub-lithographic, hard, massive, fossiliferous; *Squamularia*, large *Chaetetes* heads, and Bryozoa common	4	6
38. Shale; green to blue-gray, thin-bedded		$3\frac{1}{2}$
37. Limestone; thin-bedded, fine-grained, fossiliferous, nodular at base; abundant *Linoproductus*, *Composita*, *Dictyoclostus*, and a large species of *Chonetes; Chonetes* is particularly characteristic, being abundant enough locally to form coquina (zones 37, 38, and 39 are upper Pawnee limestone)	2	
36. Shale; dark gray to black, earthy, with nodular limestone; two coquina-like zones of *Derbya;* a few *Dictyoclostus* throughout	1	10
35. Shale; thin-bedded, blue-gray mottled with light gray clayey areas	2	4
34. Shale; black, earthy, calcareous nodules in upper part	1	5
33. Limestone (Myrick Station member of Pawnee); light gray, fine-grained, hard, conchoidal fracture; wavy bedding but weathers massive	5	5
32. Shale; black, carbonaceous, slaty	1	4
31. Coal (Lexington)	1	6
30. Shale; black, carbonaceous, earthy, fossiliferous with large *Compositas*		8
29. Underclay; blue-gray to light gray (zones 29 to 36 comprise Labette shale)	2	
28. Limestone; dove-gray to blue-gray, weathers buff, fine- to medium-grained, hard, massive, uneven upper and lower surfaces, fossiliferous (top of Fort Scott limestone = the "*Chaetetes* limestone" = the "Lexington bottom-rock" = Higginsville limestone of this report)	4	3
27. Shale; thin-bedded, light gray to almost white; upper part clayey, highly plastic when wet, stained by iron sulphates, acrid to taste ("white shale" of drillers)	6	3
26. Shale; red and green, thin-bedded, but with blocky fracture, soapy feel when wet	9	6
25. Shale; blue-gray to black, darkest below	6	6
24. Limestone; brownish gray, fine to medium-grained, hard; closely spaced joints cause it to weather into small rhomboidal blocks ("Rhomboidal limestone" of Missouri Survey = Houx limestone of this report)		9
23. Shale; black, slaty, with here and there gray phosphatic concretions ("slate vein" of miners)	1	10
22. Shale; thin-bedded, earthy; black above, dark blue-gray below; fossiliferous with many *Marginifera* and *Composita*, and a few *Dictyoclostus* and *Mesolobus*	1	10
21. Coal (Summit)		6
20. Underclay; ash-gray, plastic when wet	1	
19. Limestone; gray, weathers yellow; nodular, highly irregular bounding surfaces	1	
18. Shale; gray, poorly exposed	7	6
17. Limestone; argillaceous; gray, weathers buff; one massive, well jointed bed; fossiliferous with *Syringopora*, *Chaetetes*, and crinoid stems (lower Fort Scott = "Mulky cap rock" = Blackjack Creek limestone of this report; zones 17–28 constitute Fort Scott limestone)	2	6
Cherokee group		
16. Shale; poorly exposed; dark gray to olive-green; lenses of platy gray phosphatic concretions	2	
15. Shale and siltstone; weathers drab to yellow; lenses of sandstone.	13	6

	Feet	*Inches*
14. Sandstone; fine-grained, hard, limonitic bond, weathers brown...	2	6
13. Shale, drab	2	9
12. Limestone; thin, earthy, coquinoid; 0–6 inches		3
11. Coal (Bedford?)		6
10. Shale; blue-gray above, dark blue and carbonaceous below	14	3
9. Sandstone	7	
8. Siltstone and shale; drab sandy siltstone at top grading into dark blue-gray carbonaceous silty shale below; thin-bedded throughout	23	
7. Limonitic zone; probably is badly weathered sideritic limestone as it contains internal molds of *Marginifera* and some gastropods		4
6. Shale; dark blue-gray, almost black, with zones of pancake-like clay ironstone concretions	3	
5. Shale	13	8
4. Black shale	2	
3. Coal (Bevier)	1	
2. Underclay	1	
1. Limestone (Ardmore)	5	

Discussion of Section II

Zones 21–57 are a composite of seven sections measured in the vicinity of Lexington, Lafayette County, where several short ravines cascade down the steep south bluff of the Missouri River, exposing an excellent series of outcrops. Measurements for the composite section are principally from four of these ravines which are crossed by U. S. Highway 24 at points 0.12, 0.25, 0.85, and 1.15 miles west of Myrick Station. Of the four ravines, the one in which the most nearly complete section is exposed is the second one west of Myrick Station. Here beds ranging from the "Wayside sandstone" (?) to the Higginsville limestone may be seen.

The interval from zones 6 to 20 inclusive was measured at Houx Ranch in Johnson County, about 6 miles west of Warrensburg. The base of this section crops out in a south-side cutbank of Blackwater Creek and the upper part is exposed in hillside cutbanks of a private road about ¼ mile south of the creek. Beds lower than zone 6 are after the Missouri Survey.

DES MOINES SERIES

CHEROKEE GROUP

The most important limestone in the Cherokee group is the Ardmore (zone 1). Despite its thinness this bed has remarkable distribution; southwestward it extends to the vicinity of Tulsa, Oklahoma (the Verdigris limestone of northeastern Oklahoma); it has been traced as far as northern Guthrie County, Iowa (Cline, 1938, p. 1873). Throughout this area it is a valuable marker in an interval where persistent and diagnostic units are generally wanting.

Because of stratigraphic position the coal at zone 11 is tentatively identified as the Bedford.

HENRIETTA GROUP

Fort Scott limestone.—From the Missouri River northward the Fort Scott formation includes portions of three cyclothems. At the type section in southeastern Kansas the formation is predominantly limestone, but northeastward in Missouri shale becomes increasingly prominent, and in the latitude of the Missouri River, shale is the predominating rock type, and if the formation has been correctly traced, there are three limestone members. In ascending order these limestones are called by the Missouri Survey: the lower Fort Scott ("Mulky cap rock"), the "Rhomboidal," and the upper Fort Scott ("Lexington bottom-rock").

These three thin limestones persist from the Missouri River far into Iowa. They belong to three different cyclothems and should be given separate names. If the Missouri Survey sees fit to retain Fort Scott as a formation name, the geographic names herein applied to these limestones should be regarded as member names. If it is decided to discontinue the use of the term Fort Scott as a formational name, the member names should be elevated to formation rank.

Frank C. Greene of the Missouri Survey has been asked to suggest appropriate names for the three limestone members of the Fort Scott formation and he (letter dated, January 5, 1940) has kindly consented. Greene proposes to substitute the name Blackjack Creek limestone for lower Fort Scott. For a type locality he refers to outcrops in Johnson County mentioned by Hinds (1912, p. 220); "Four miles southeast of Fayetteville and along Blackjack Creek the Mulky [coal] and its typical cap-rock [lower Fort Scott limestone] may be seen on the low divides." Houx limestone is proposed for the "Rhomboidal limestone." It is well exposed at Houx Ranch, in Sec. 15, T. 46 N., R. 27 W., in Johnson County, Missouri. For upper Fort Scott limestone the term Higginsville is suggested. It is well exposed east of Higginsville (Hinds, 1912, pp. 242, 243).

The Blackjack Creek limestone is, by definition, the base of the Marmaton group in Kansas and the Henrietta group in Missouri. This thin but persistent limestone and the underlying black shale and Mulky coal form a valuable datum plane both on the surface and in the subsurface. A more natural boundary between the Henrietta and Cherokee groups is perhaps an unconformity a short distance below the Mulky coal. The unconformity is ordinarily inconspicuous, even on the outcrop, but the development of a widespread channel sandstone in the interval between the Mulky and Bedford coals in many parts of Missouri and Iowa speaks eloquently of its stratigraphic importance. The many channel fillings in the Lagonda shale, such as the

"Squirrel sandstone" of drillers, which locally cut through the Bedford and Bevier coals and underlying Ardmore limestone to rest on lower Cherokee beds, are probably to be referred to the Blackjack Creek cyclothem for the most part.

The Houx limestone is rarely more than a foot thick in central and northern Missouri but it is exceedingly persistent and, with the underlying black shale of the Summit coal horizon, it forms an excellent key bed. The Summit coal is thought to be the exact equivalent of the coal between the upper and lower limestones of the Fort Scott formation of Kansas.

Labette shale.—The Labette shale at the type section in Labette County, Kansas, includes the beds between the Pawnee and Fort Scott limestones. The term has been incorrectly used in Missouri, having been applied to the entire interval from the base of the upper Pawnee limestone down to the top of the Higginsville limestone.

The Lexington coal and its "cap rock," the Myrick Station limestone, constitute the best markers in the Henrietta group in the area north of the Missouri River, both on the outcrop and in the subsurface.

Pawnee limestone.—At the conclusion of the recent field conference in which the Missouri, Kansas, and Iowa surveys participated, it was agreed that the Pawnee limestone of Kansas splits into two limestones separated by shale as it is traced from Kansas into Missouri. The upper limestone split is the "Pawnee" (of current usage) of west-central Missouri. It is henceforth to be regarded as a member of the Pawnee formation. Moore and Jewett have agreed to select an appropriate name for this limestone and designate as a type section some locality in southeastern Kansas.

For the lower limestone member of the Pawnee (the "Lexington cap rock" of Missouri Survey terminology) the writer proposes the name Myrick Station, designating as the type section outcrops in ravines in the south bluff of the Missouri River near Myrick Station on the Missouri Pacific Railroad, just west of Lexington, Lafayette County, Missouri.

Bandera shale.—The succession of beds from the Worland down to the Pawnee is shale (zones 42 to 46), coal (zone 41), clay, and shale (the last two members are undifferentiated in zone 40). In several outcrops sandstone occupies the lower part of the interval and rests with evident unconformity on various horizons within zone 40. This sandstone was probably deposited after the formation of the coal of zone 41, for in two of the exposures sandstone occupies the horizon where the coal would be expected. The shale interval between the Altamont

and Pawnee limestones increases from 2 feet in eastern Jackson County to about 20 feet at Lexington. This variation in thickness is doubtless explained by the unconformity.

Altamont limestone.—The Tina limestone member of the Altamont is absent or poorly developed in the vicinity of Lexington but this does not preclude the possibility that it is present elsewhere in Lafayette County. The Tina normally occupies a place in the section beneath the coal smut of zone 43. The dark shale of zone 45 persistently carries a zone of ash-gray phosphatic concretions which aid in differentiating the Worland and Tina limestones farther north in Missouri and, according to Jewett (personal communication), this zone consistently occurs between the lower and upper Altamont limestones in southeastern Kansas.

The Worland limestone has repeatedly been confused with the upper Pawnee. In Marbut's description (1898, pp. 213, 219) of the Henrietta group at Lexington the topmost bed of his Section III is the Worland and so is zone 9 of his Section XIV.

Lenapah? limestone.—On the basis of its position in the section zone 52 is questionably identified as the Lenapah limestone. Zone 51 is thus tentatively identified as the Nowata.

MISSOURI SERIES

PLEASANTON GROUP

The sandstone at zone 57 is referred to the Missouri series and is provisionally correlated with the "Wayside sandstone" of Section I. The sandstone occupies the same stratigraphic position relative to the Lenapah limestone in Lafayette County as the basal sandstone of the Missouri series occupies with respect to the Lenapah in southeastern Kansas. The possibility is suggested that zone 57 is equivalent to the Warrensburg sandstone of Johnson County, Missouri.

SECTION III

NORTHEAST OF HARDIN, RAY COUNTY, MISSOURI

Top	*Feet*	*Inches*
Des Moines series		
Henrietta group		
23. Limestone (Lenapah?); impure, fossiliferous with crinoid stems, *Composita*, and a few pelecypods		10
22. Shale; drab, silty	21	
21. Shale; red platy	2	
20. Green clay; nodules of ferruginous limestone in lower part	2	
19. Limestone (Worland); massive above, becomes shaly below and carries algal pellets; light gray and sub-lithographic above; upper surface irregular; fossiliferous	2	6
18. Limestone; light gray, fossiliferous with many *Chaetetes* heads along bedding planes and with rather large fat fusulinids; composed of several wavy beds but appears fairly massive on weathered surface (zones 18 and 19 are Worland limestone)	2	
17. Shale; green, thin-bedded, fossiliferous	3	
16. Shale; dark blue-gray to black		$1\frac{1}{2}$

	Feet	Inches
15. Shale, siltstone, and sandstone; interval highly variable; poorly bedded, green, micaceous, silty shale that breaks with a blocky fracture; replaced laterally by red and green mottled shale and siltstone mixed with fine- to medium-grained sandstone that shows some cross-bedding and weathers yellow to buff; thickness varies from $6\frac{1}{2}$ to 17 feet, averaging 13 feet	13	
14. Conglomerate; pebbles and fragments of medium gray limestone in matrix of fine- to medium-grained, slightly fossiliferous limestone; weathered surface easily mistaken for limestone; 0–$1\frac{1}{2}$ feet, averaging 6 inches		6
13. Dark carbonaceous shale		$\frac{1}{2}$
12. Limestone; dove-gray, sub-lithographic, fossiliferous; *Derbya* abundant; fossils darker than matrix; 0–5 inches		$2\frac{1}{2}$
11. Clay; green mottled with red; greatest observed thickness where zone 12 is absent; averaging 8 inches but ranging up to 14 inches.		8
10. Carbonaceous streak		$\frac{1}{2}$
9. Limestone; lithology like zone 12; nodular, fossiliferous; 0–7 inches		$3\frac{1}{2}$
8. Green clay	5	
7. Limestone (upper Pawnee); medium-gray, fine to medium-grained, weathers brown to buff; massive, upper surface irregular; many *Chaetetes* and *Squamularia*	3	6
6. Shale and limestone; calcareous shale and nodular limestone, grading from marl to impure limestone along strike; at some localities in Richmond district there is more or less continuous limestone from top of the Pawnee to base of Myrick Station; shale very fossiliferous throughout; *Derbya*, *Mesolobus*, and large *Chonetes* abundant; large *Chaetetes* colonies in upper part...	5	8
5. Limestone (Myrick Station); thin, wavy beds above, becoming more massive below	2	6
4. Shale; black, slaty; 0–1 foot, averaging 6 inches		6
3. Coal; $1\frac{1}{2}$–2 feet (Lexington)	1	9
2. Clay; reported in mines	2	
1. Limestone; not observed but reported in mines (Higginsville)....	5	

Discussion of Section III

Section III is a composite of several exposures and outcrops in the Missouri River bluffs northeast of Hardin, Ray County, Missouri. Zones 1–19 are well shown in ravines on the north side of the east-west road in the SW. $\frac{1}{4}$ of Sec. 13 and the east-central part of the SE. $\frac{1}{4}$ of Sec. 14, both in T. 52 N., R. 26 W. Zones 20–23 are exposed in ditches of the north-south road in the hill in the SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 14.

Pawnee limestone.—There is such complete gradation between the upper and lower limestone members of the Pawnee through the calcareous shale and marl of zone 6 that it is difficult to determine the exact boundaries of each member.

Bandera shale.—The rapid variation in thickness of the interval between the Pawnee and Altamont limestones is caused by an unconformity. In some of the exposures northeast of Hardin, a thin limestone conglomerate seems to mark the base of the unconformity. The degree of development of the conglomerate varies greatly in short distances and in many exposures it is absent, but it is locally found in a wide area. Near the center of the SE. $\frac{1}{4}$ of Sec. 14, T. 52 N., R. 26 W.,

cross-bedded sandstone seems to occupy the entire interval between the Worland and the Pawnee.

Worland limestone.—*Chaetetes* and fusulinids continue to characterize the Worland limestone and, as at Lexington, it consists of two beds of limestone separated by thin fossiliferous marl. The Tina member of the Altamont does not seem to be developed near Hardin.

Lenapah limestone?—The thin inconspicuous limestone tentatively identified as the Lenapah is rarely seen on the outcrop because the adjacent Pleasanton and Nowata shales weather to grassy slopes. Marbut (1898, p. 279) described this bed in one of his sections and possibly in another, but it was miscorrelated and he apparently was not aware that the bed is persistent. The writer has not observed the limestone north of Section III.

SECTION IV

Livingston and Northern Carroll Counties, Missouri

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
40. Hertha limestone		
Pleasanton group		
39. Shale, siltstone, and sandstone; lithology varies from predominantly shale and siltstone to massive but cross-bedded, medium-grained, soft, micaceous yellowish sandstone that weathers yellow to brown; unconformable on underlying beds; locally cuts out all beds down to Worland limestone, in which case thickness may be as great as 165 feet; Ovid coal is said to occur 15 feet below Hertha and at some places there is coal near base of Pleasanton	130	
Des Moines series		
Henrietta group		
38. Limestone; blue-gray, weathers brown; dull, earthy, sparingly fossiliferous with *Chonetes* and *Trepospira* (Exline limestone)		5½
37. Poorly exposed interval; complete thickness not observed at one locality but composed predominantly of gray shale and siltstone with some red shale	27	
36. Limestone (Worland); dense, fine-grained, light gray, weathers brown; contains large fusulinids; 2–5½ feet	3	
35. Shale; green-gray, calcareous, highly fossiliferous; containing considerable nodular limestone; dark shale streak near base contains a zone of almond-shaped phosphatic concretions	2	
34. Carbonaceous streak		
33. Clay; green but locally mottled red; calcareous nodules in lower part; 3–9 feet	5	
32. Limestone (Tina); light gray, weathers buff; many *Squamularia*, fusulinids, and with thin wavy colonies of *Chaetetes* distributed along bedding planes; wavy, irregular beds; upper surface algal and irregular; base nodular and argillaceous, more massive above	4	4
31. Shale or clay; poorly exposed, lower 4 feet red	12	6
30. Limestone (top of Pawnee); badly weathered to buff, argillaceous marl; contains *Composita* and *Neospirifer*	2	
29. Shale; green		6
28. Marl; weathers buff		6
27. Shale; bright green, hard, platy to fissile	1	4

	Feet	Inches
26. Limestone and shale; thin-bedded, nodular, argillaceous limestone and calcareous shale, limestone predominating; very fossiliferous with *Derbya*, a large species of *Chonetes*, and large crinoid stems; *Marginifera, Neospirifer, Composita*, and *Mesolobus* less abundant (zones 26–30 are the Pawnee limestone)	4	
25. Shale; green-gray above, dark gray below and with zone of ash-gray phosphatic concretions	1	
24. Coal smut (Lexington)		¼
23. Clay; green below, dark gray to almost black above	2	6
22. Limestone (Higginsville); massive, medium-grained, argillaceous, ferruginous, weathering to deep limonitic brown, upper surface algal and irregular	3	10
21. Sandstone, siltstone, and shale; fine to medium-grained, friable, micaceous sandstone in upper part; thin-bedded to massive with some cross-bedding; thin-bedded, dark blue-gray silty micaceous shale below	24	
20. Limestone (Houx); hard, dense, fine-grained, sub-conchoidal fracture, massive, dark blue-gray, weathers yellow; well developed and closely spaced joints cause it to weather into rhomboidal slabs; a few crinoid stems; 8 inches to 2 feet	1	4
19. Gray shale	1	
18. Shale; black, slaty, almond-shaped phosphatic concretions give it pimply appearance	1	6
17. Marl; laminated, shaly in places, but laterally grades into soft limestone; very fossiliferous; *Marginifera, Composita*, and *Mesolobus; Marginifera* especially abundant		10
16. Coal (Summit); in places represented by black shale		3
15. Shale; earthy, calcareous, fossiliferous; 0–2½ inches		1½
14. Clay; blue-gray, calcareous nodules in lower part	4	6
13. Limestone (Blackjack Creek); light blue-gray, weathers buff; argillaceous, sparingly fossiliferous	2	8
Cherokee group		
12. Shale; predominantly dark gray but with olive-green streaks; black zones which contain disc-like lenses of gray phosphatic concretions	2	
11. Marl; laminated carbonaceous earthy limestone with many shell fragments; 0–4 inches		2
10. Coal smut (Mulky)		½
9. Clay; blue-gray, blocky	3	
8. Sandstone and siltstone; fine-grained, green sandstone, weathers yellow, mixed with subordinate quantities of thin-bedded, micaceous siltstone that weathers drab	9	
7. Shale and siltstone; red and green mottled, thin-bedded	5	
6. Sandstone; fine-grained, thin-bedded, interlaminated with siltstone, whole weathering drab; grades into massive to cross-bedded light-colored sandstone which locally channels out Bedford coal and subjacent strata	32	
5. Coal (Bedford); in places cut out by sandstone of lower part of zone 6; 0–28 inches	2	4
4. Shale, siltstone, and sandstone; underclay at top; black slaty shale at base	14	
3. Limestone; black, pyritic, fossiliferous; 0–10 inches		5
2. Coal; 0–4 inches (Bevier)		4
1. Clay	3	

Discussion of Section IV

Poor outcrops and an unconformity at the base of the Pleasanton combine with some reversals in dip greatly to hinder the lateral tracing of beds in Livingston County.

DES MOINES SERIES

CHEROKEE GROUP

Zones 6–12 are well exposed in cutbanks of an east-west road in the hill east of the school, in the SW. ¼ of Sec. 1, T. 56 N., R. 22 W., in Livingston County. Zones below the Bedford coal are after a section that Hinds (1912, pp. 264, 265) measured near the town of Bedford, in the NE. ¼ of Sec. 11, T. 56 N., R. 23 W.

Lagonda shale.—The Lagonda shale has many of the characteristics that it exhibits in Section II. In the type area the Bedford coal attains a thickness of 28 inches but is missing locally where the basal sandstone of the overlying Blackjack Creek cyclothem channels through it to rest on older formations. Hinds and Greene (1915, pp. 51, 52) reported that the Bedford and Bevier coals are so close in eastern Linn and Chariton counties as to form virtually one bed, the interval between them gradually decreasing eastward. They believed the Bedford to be a split from the Bevier. Grohskopf, Hinchey, and Greene (1939, p. 21) are still of this opinion, although they are at a loss to explain such unequal rates of sedimentation.

HENRIETTA GROUP

The thickness of the shale between the Exline and Worland limestones was obtained by barometer readings. The Worland and Tina limestones are described from exposures in quarries in the west-central part of Sec. 7, T. 54 N., R. 22 W., in Carroll County. Measurements of beds from the Tina to the base of the Higginsville are from quarry exposures on both sides of the east-west road in the SW. ¼ of Sec. 30, T. 60 N., R. 22 W., just west of Alpha, Grundy County, and about one mile north of the Livingston County line, but the descriptions are supplemented from studies of numerous isolated outcrops and exposures in Livingston County. Zones 13–21 are well exposed in roadside cutbanks along U. S. Highway 65 in the NW. ¼, SW. ¼ of Sec. 25, T. 57 N., R. 24 W. and in the east-west road in the SW. ¼ of Sec. 1, T. 56 N., R. 22 W., both in Livingston County.

Houx limestone.—The Houx limestone, black slaty shale, fossiliferous marl, Summit coal, and underclay of the Houx cyclothem are remarkably similar to their counterparts in Section II.

Pawnee limestone.—When the Hinds (1912) and Hinds and Greene (1915) reports were published, the Worland and Tina limestones had not been differentiated and named. Where mention was made of outcrops of these limestones they were confused with the Pawnee. The writer does not know of any place in Livingston or northern Carroll counties where the complete interval from Worland to Pawnee is well

exposed. To add to the difficulties of study, the first limestone below the Exline is not everywhere the Worland. Post-Henrietta, pre-Pleasanton erosion removed the Worland and Tina limestones at several places in Livingston County and the Pleasanton rests with distinct unconformity on the Pawnee.

The upper and lower limestones of the Pawnee are undifferentiated in Section IV. The writer is inclined to regard zone 26 as the Myrick Station member and to refer zones 28–30 to the upper limestone member. However, R. C. Moore (personal communication, May, 1940) is of the opinion that the Myrick Station member is not developed in this area and that all of the Pawnee should be referred to the upper member. The limestone carries a prolific fauna of *Composita*, a large species of *Chonetes*, *Dictyoclostus*, *Mesolobus*, *Derbya*, *Neospirifer*, *Ambocoelia*, *Enteletes*, *Archeocidaris* spines, and large crinoid stems. *Derbya* and the large *Chonetes* are especially abundant in the upper member of the Pawnee at Lexington (Section II) and lend some strength to Moore's correlation.

Altamont limestone.—The Tina member of the Altamont again becomes well developed in northern Carroll County. The type locality of this member is southeast of Tina, in the west-central part of Sec. 7, T. 54 N., R. 22 W., where together with the Worland limestone it has been quarried on both sides of the east-west road.

The Worland member continues to carry *Chaetetes* and abundant representatives of a rather plump species of fusulinid. This limestone is massive, algal, and, unlike most of the Henrietta limestones, it is light gray upon weathering.

Exline limestone.—The Exline limestone (*Trepospira* zone) has not heretofore been identified in Livingston County. It is well exposed in cutbanks along U. S. Highway 65, in the NW. ¼ of Sec. 16, T. 56 N., R. 23 W.

MISSOURI SERIES

Pleasanton group.—In Livingston County and in northern Carroll County outcrops of the Pleasanton are chiefly west of U. S. Highway 65. Some of the thickest and best exposures are: near Stokes Mound, Carroll County; in the bluffs on the south side of Grand River west of Utica; and along Thompson River northwest of Chillicothe, Livingston County. The descriptions and measurements given are primarily from exposures in and near a clay pit in the northwest edge of Utica, the old Graham Mill exposure in the NE. ¼ of Sec. 21, T. 58 N., R. 24 W., and the old Gillespie Mill exposure in the west bluff of Thompson River in the SE. ¼ of Sec. 27, T. 59 N., R. 24 W.

The Pleasanton group is subject to such rapid vertical and lateral variation in Livingston County, and exposures are generally so poor that, with the exception of the Ovid coal, individual units of the Pleasanton have not been traced for any considerable distance. Another possible exception is a coal that, although not everywhere present, is frequently found near the base of the group.

In the high hill west of Utica the Pleasanton is so largely composed of shale and siltstone that it is utilized in making brick and tile, whereas a short distance upstream there is considerable sandstone in the south bluff of the river, and at Gillespie's Mill 86 feet of brown, massive, cross-bedded, bluff-forming sandstone was measured by Hinds and Greene (1915, p. 82).

The variation in thickness of the Pleasanton is explained by the unconformity at its base. At Utica 165 feet of Pleasanton rests with apparent unconformity on the Pawnee limestone, and seemingly cuts out the Exline limestone. About ½ mile northwest of Utica a coal is present beneath a massive sandstone in the lower part of the Pleasanton. At Graham Mill, northwest of Chillicothe, the coal rests with distinct angular unconformity on the Pawnee limestone, truncating about 4½ feet of the limestone in a horizontal distance of less than 20 yards; the Pawnee and Higginsville limestones dip steeply downstream, but the overlying 133 feet of thin-bedded Pleasanton sandstone is essentially horizontal. There is much red and green shale in the lower Pleasanton of Carroll County, and according to Hinds (1912, p. 123) the basal coal is absent. This coal was miscorrelated as Mulberry by Hinds and Greene (1915, p. 82).

SECTION V

DAVIESS AND GRUNDY COUNTIES, MISSOURI

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
21. Hertha limestone		
Pleasanton group		
20. Carbonaceous streak		
19. Siltstone, sandstone, and shale; thinly stratified siltstone with varying amounts of shale and sandstone, or mostly sandstone; locally 2½ feet of underclay developed at top	14	
18. Coal smut; may be replaced by sandstone (Ovid)		
17. Underclay	3	
16. Sandstone, siltstone, and shale; lithology highly variable, changing from siltstone with subordinate amounts of sandstone to medium-grained, micaceous, cross-bedded, massive, cliff-forming sandstone that weathers yellowish brown; sandstone is predominating rock type in areas of best outcrops; in some areas, well developed coal bed near base; unconformable on underlying beds, locally cutting through Henrietta and resting on Cherokee; averaging 110 feet; maximum thickness attained where unconformity is best developed	110	

	Feet	Inches
Des Moines series		
Henrietta group		
15. Shale; thin-bedded, red and green	7	
14. Limestone; argillaceous, fossiliferous		3
13. Shale		3
12. Carbonaceous streak		
11. Clay; green mottled with red	1	11
10. Limestone (top of Worland); light gray, weathers buff, upper surface nodular, irregular, algal; fossiliferous with *Ambocoelia* and *Chonetes*	2	6
9. Shale; green, contains many *Ambocoelia*		10
8. Limestone; argillaceous, weathers buff; 1–3 inches		2
7. Shale; olive-green with some dark gray to black streaks near base	1	6
6. Carbonaceous streak		
5. Clay; zones 24–29 belong to Worland cyclothem	1	6
4. Shale; green with some nodular limestone		7
3. Carbonaceous streak		
2. Clay; green-gray, with calcareous nodules in lower part	2	2
1. Limestone (Tina); medium gray, weathers buff, fossiliferous with *Composita*		8½

Discussion of Section V

Descriptions of zones from the Hertha limestone down to the Ovid coal are from exposures near Gallatin, Daviess County. The upper and middle Pleasanton are well exposed in the bluffs of Thompson River just west of Trenton, and the lower part of this group is exposed south of Laredo, both in Grundy County. The Worland and Tina limestones are described from exposures in the SW. cor. of Sec. 23, T. 60 N., R. 24 W.

DES MOINES SERIES

Henrietta group.—Outcrops of the Henrietta are limited principally to the southeast part of Grundy County. South of Laredo and in the vicinity of Alpha a composite section from the Worland to below the Higginsville is exposed, though poorly so. In this area there is present just above the Worland limestone a cyclothem that was not observed in Livingston County. It consists of two feet of red and green mottled clay, a coal smut, a thin calcareous shale, a thin fossiliferous limestone and several feet of red and green shale, in ascending order. The cyclothem persists northward well into Iowa but its southern limit is not known.

The lower one of the two coal smuts developed between the Worland and Tina limestones seemingly has no correlative in previously described sections of the traverse.

The Exline limestone has not been reported from Grundy County which points to the conclusion that it was removed by pre-Pleasanton erosion.

MISSOURI SERIES

Pleasanton group.—Sandstone is the most conspicuous element in the Pleasanton of Grundy County. In the hill just west of Trenton, along Missouri State Highway 6, massive yellow-brown sandstone extends downward for more than 50 feet below the Hertha limestone. According to Hinds and Greene (1915, p. 83), drillings at Trenton have revealed that locally the Pleasanton rests directly on Cherokee beds, and they state that "at the Main Street bridge over Grand River the unconformity is plainly exposed, with a layer of conglomerate resting on the various beds of the Henrietta."

Whether the massive sandstone exposed west of Trenton extends all the way down to this unconformity is not clear. This problem is important because of its bearing on the stratigraphic position of the Des Moines-Missouri boundary. McQueen and Greene (1938, p. 22) are of the opinion that this massive sandstone is closely associated with the Knobtown sandstone of the Kansas City area and that it probably has no relation to the Warrensburg. With further reference to the unconformity at the base of the Pleasanton, Hinds and Greene (1915, p. 83) are again quoted:

> In the central and southeastern portions of the county [Grundy] the Pleasanton unconformity is well marked, the lower part of the Pleasanton and all or a part of the Henrietta having been removed prior to the deposition of the sandstone, sandy shale, and coal of the upper part of the Pleasanton.

SECTION VI

SULLIVAN COUNTY, MISSOURI

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
85. Hertha limestone		
Pleasanton group		
84. Shale; gray, calcareous, fossiliferous; *Marginifera* present	2	
83. Coal		3
82. Underclay; gray, calcareous nodules in lower part	2	
81. Shale; gray	5	6
80. Sandstone; fine-grained, yellow, micaceous	1	
79. Shale; upper half silty, dark gray below	4	6
78. Coal; locally as thick as 30 inches, averaging 6 inches (Ovid)		6
77. Underclay	1	
76. Siltstone; thin-bedded, shaly, weathers drab, grades into zone 75 below	5	
75. Sandstone; fine- to medium-grained, soft, mealy, micaceous, weathers yellowish; probably green when fresh	10	
74. Shale, siltstone, and sandstone; interval highly variable; may be mostly siltstone or predominantly sandstone, but lower part rather consistently contains considerable sandstone which either replaces or cuts out basal shale and siltstone	60	
Des Moines series		
Henrietta group		
73. Shale; blue-gray, very dark at top	2	6

	Feet	*Inches*
72. Impure limestone (Exline); varies from impure dark blue-gray argillaceous limestone to calcareous shale with lenses of limestone; very fossiliferous; *Trepospira* and *Euphemus* are especially characteristic	1	6
71. Shale; blue-gray, thin-bedded, stained with limonite	3	
70. Coal; 0–2 inches		1
69. Underclay; plant remains and carbonaceous streaks; 2½ feet exposed	2	6
68. Covered	2	
67. Shale; green-gray	4	
66. Covered; zones 66–71 are replaced laterally by thin-bedded, red, silty shale	4	
65. Sandstone; thin-bedded, micaceous, green, weathers yellow-brown	8	
64. Shale; green	1	
63. Shale; dark, soft to slaty		10
62. Green shale		4½
61. Carbonaceous smut		
60. Underclay; green, root marks		7
59. Clay ironstone		1½
58. Shale; platy; green with brown stains		6
57. Shale; green above, becoming black and carbonaceous below		1½
56. Gray shale		1
55. Coal smut		
54. Underclay		7
53. Shale; green and blue-gray mottled with red; weathers to a red soil	5	
52. Shale; platy, very dark and carbonaceous at base	2	
51. Coal smut		
50. Underclay		8
49. Covered	3	
48. Limestone (top of Worland); massive ledge of hard, light gray limestone enclosing small pockets of green clay; upper surface irregular; abundantly fossiliferous; large fat fusulinids, small variety of *Mesolobus*, *Ambocoelia*, and Bryozoa	1	8
47. Shale and nodular limestone; green with some dark streaks; limestone-shale ratio varies greatly in short distances; fossiliferous; *Ambocoelia*, *Marginifera*, small *Mesolobus*, a trilobite, and large crinoid stems	1	6
46. Shale; green, lower one inch black		10
45. Shale; gray, brownish on weathering; calcareous		4
44. Impure limestone; 0–3 inches		1½
43. Carbonaceous streak		
42. Clay; green-gray (zones 42–48 constitute Worland cyclothem)	2	6
41. Shale; green and platy	3	
40. Limestone; argillaceous, weathers buff; fossiliferous, with *Linoproductus*, and large *Composita*		4
39. Marl; weathers buff, grades into zone 40 and contains same fauna (zones 39 and 40 are Tina limestone)	1	2
38. Carbonaceous streak		
37. Clay; maroon above, green below; locally 2 feet of sandy material at top	8	

(Following descriptions are from published subsurface data. Parenthetical remarks are those of the writer)

Top	*Feet*	*Inches*
36. Shale and siltstone	10	
35. Limestone (Pawnee)	2	
34. Shale		6
33. "Hard rock" (probably part of Pawnee)	1	
32. Shale	2	

	Feet	Inches
31. Shale; black, slaty (Lexington coal horizon)	2	
30. "Soapstone" (underclay)	3	
29. "Shale and rock mixed"	3	
28. "Hard flinty rock" (zones 28 and 29 are Higginsville limestone)	1	9
27. "Blue slate" (shale and siltstone)	15	
26. Dark shale	4	1
25. "Rock" (Houx limestone)		5
24. Black shale (Summit horizon)	3	2
23. "Rock" (impure fossiliferous limestone commonly found beneath Summit coal)		5
22. "Dark shale"	2	
21. "Light shale" (underclay)	5	
20. "Rock"	1	
19. "Light blue shale"	1	4
18. "Hard rock" (zones 18–20 correlated with Blackjack Creek limestone)	1	9
Cherokee group		
17. Shale; hard, blue	1	6
16. Dark shale (Mulky coal horizon)	2	
15. "Hard light blue shale"	10	5
14. "Rock"		8
13. Shale (Blackjack Creek limestone, according to Missouri Survey, but not according to present interpretation)	1	
12. "Soapstone"	6	
11. Coal and black slaty shale (Bedford; Missouri Survey correlation would be Mulky, since they recognize zone 13 as base of Henrietta)		8
10. Green shale	3	
9. Shale	33	6
8. Coal	3	3
7. "Bench rock"		6
6. "Black band"		6
5. Coal; zones 5–9 are Bevier coal		7
4. Underclay	2	9
3. "Gray rock"	4	5
2. "Clay"	2	
1. Limestone (Ardmore)		8

Discussion of Section VI

Zones 75–85 were measured in cutbanks along County Highway E, in the hill west of Locust Creek, in the NW. ¼ of Sec. 5, T. 63 N., R. 20 W. The interval included in zones 73 and 74 was measured in the NE. ¼ of Sec. 13, T. 61 N., R. 21 W., in a southeastward-flowing ravine, just east of a north-south road, where beds from the Hertha limestone to below the Exline limestone may be seen. Measurements from the Exline (zone 72) to zone 39 are taken from roadside cutbanks in the hill east of the bridge over Locust Creek, in the NE. ¼ of Sec. 8, T. 61 N., R. 20 W., and in ravines in pastures north and south of the road. Zones 37 and 38 were measured north of Green City, in cutbanks of a creek in Sec. 34, T. 64 N., R. 18 W.

A comparison of available logs of coal test borings in Sullivan County shows so much variation that the writer hesitates to construct a generalized section for beds below the Tina limestone. In most of the logs it is easy to identify the Summit and Bevier coals, but other hori-

zons are more difficult to determine. The log of W. R. Morgan's coal test (Grohskopf, Hinchey, and Greene, 1939, pp. 152, 153) near Milan has been selected to give the intervals between the coals and limestone but the descriptions are supplemented by published logs of other coal tests in the county. There is little doubt that the limestone topped at 82 feet and 1 inch in the Morgan test is the Worland, and that the coal at 215½ feet is the Bevier.

DES MOINES SERIES

CHEROKEE GROUP

On the interpretation that zone 13 is the base of the Fort Scott limestone, the Missouri Survey (Grohskopf, Hinchey, and Greene, 1939, p. 152) correlated zone 11 (of the generalized section) as the Mulky coal. It is believed that this coal is the Bedford. Failure to report the Bedford in most of the coal tests is probably to be explained by the channeling at the base of the Blackjack Creek cyclothem.

Throughout Sullivan County the Bevier coal averages about 18 inches and has been worked by a number of shaft mines. The coal has been reported in practically all of the deep borings. The "gray rock" (zone 3) logged beneath the Bevier underclay may be part of the Ardmore limestone.

HENRIETTA GROUP

The base of the Pleasanton is from a few to several feet above the Exline limestone, depending on the magnitude of the unconformity at the base of the group. The Pleasanton-Henrietta contact is clearly defined at some places where sandstone or conglomerate is present but otherwise it is inconspicuous.

Pawnee limestone and Lexington coal.—In northeastern Sullivan County the Lexington coal, barely above drainage, is thick enough to be mined. South of a line drawn between Milan, Sullivan County, and Kirksville, Adair County, the position of the coal is marked by a mere smut. Good exposures of the Lexington horizon and its "cap rock," the Pawnee limestone, are rare. The bridge over Locust Creek in the NW. ¼ of Sec. 8, T. 61 N., R. 20 W., rests on the Pawnee limestone which produces a small falls in the stream. The section exposed at the bridge is as follows:

Top	*Feet*	*Inches*
5. Limestone; gray, medium-grained, hard, weathers yellow; fossiliferous with large species of *Chonetes, Enteletes, Derbya, Dictyoclostus*, and large crinoid stems	1	4
4. Shale and limestone; calcareous shale and nodular limestone; very fossiliferous with *Derbya* and *Chonetes*	1	6
3. Shale; green above, black below and almost slaty	1	6
2. Coal smut (Lexington horizon)		
1. Clay; green; exposed	1	2

The Worland and Tina limestones are exposed in the hill at the east.

Altamont limestone.—Both the Tina and Worland members of the Altamont have about the same lithologic characteristics as in Sections IV and V, but the lower of the two coal smuts present between the limestones in outcrops near Laredo, Grundy County, does not seem to be represented in Sullivan County.

The unusual thickness of the underclay of the Tina cyclothem is noteworthy. In the northeastern part of the county there are at least 8 feet of red and green mottled clay, which is abnormally thick for the Pennsylvanian clays of northern Missouri and southern Iowa.

Younger Henrietta beds.—The clay and coal shown as zones 69 and 70 are not everywhere present, being represented laterally by red and green mottled shale.

During the course of the writer's field work in Sullivan County no evidence of an important unconformity between the Exline and Worland limestones was found. According to the Missouri Survey, the Pleasanton-Henrietta break is in this interval. The Exline limestone, included in the Pleasanton in all former reports, is here placed in the Henrietta group because of an unconformity which comes above it and at the base of a massive sandstone. The unconformity is not quite as evident in Sullivan County as it is to the east in Adair County, but the base of the sandstone shown as zone 74 is found at varying heights above the Exline and in at least one place in the county a thin conglomerate occurs at the base. Hinds and Greene (1915, p. 86) miscorrelated the Exline as the Altamont in a section that was considered to be representative of the Pleasanton of northeastern Sullivan County (outcrops along a creek in Sec. 4, T. 63 N., R. 18 W., and Sec. 34, T. 64 N., R. 18 W.).

MISSOURI SERIES

Pleasanton group.—The thin coal at zone 83 was miscorrelated as Ovid in the section that Hinds and Greene (1915, p. 84) measured in Sec. 7, T. 61 N., R. 20 W., where it is not now well exposed. In the adjacent Sec. 13, T. 61 N., R. 21 W., this coal was exposed by digging and it is no more than 3 feet below the base of the Hertha. The Ovid coal (zone 78) occupies a slightly lower stratigraphic horizon, and although not everywhere present, in some places it is thick enough to be mined. Along County Highway E, in the hill east of Locust Creek and in the NW. ¼ of Sec. 3 (?), T. 63 N., R. 20 W., the Ovid is about a foot thick and is overlain by several feet of cross-bedded sandstone. In the hill west of the creek, in the NW. ¼ of Sec. 5, T. 63 N., R. 20 W., the Ovid is separated from the overlying coal by 13 feet of shale, siltstone, and sandstone.

The lithology of zone 74 is highly variable. In Sec. 7, T. 61 N., R. 20 W., and in Sec. 13, T. 61 N., R. 21 W., it is made up of thinly bedded blue-gray siltstone with subordinate amounts of shale and lenses and pockets of sandstone. North of Queen City, 53 feet of soft, mealy, yellow, micaceous, cross-bedded sandstone is exposed in the hill south of the bridge in the NE. ¼ of Sec. 19, T. 64 N., R. 18 W. At Boynton there is 40 feet of sandstone in this interval with several inches of conglomerate at the base (Hinds and Greene, 1915, p. 86).

SECTION VII

ADAIR COUNTY, MISSOURI

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
73. Hertha limestone		
Pleasanton group		
72. Covered	25	
71. Black shale	3	
70. Coal (Ovid); reported thickness, 2½ feet	2	6
69. Sandstone; yellow to brown; soft, friable, micaceous; massive, cross-bedded to structureless; unconformable on underlying beds, locally channeling downward as much as 12 feet; base in some places conglomeratic and at one locality conglomerate near middle	64	
Des Moines series		
Henrietta group		
68. Shale; dark blue-gray above, black and platy below	5	6
67. Limestone (Exline); varies from impure silty limestone to calcareous siltstone with lenses of blue-gray lithographic limestone; very fossiliferous; many *Trepospira*, and *Schizostoma*, a few clams	1	
66. Shale; silty and drab	2	6
65. Coal		7
64. Underclay; ash-gray to dark gray, carbonaceous	1	
63. Shale; main part thin-bedded, blue to green-gray, weathers drab; lower 3½ feet red	11	
62. Shale; green to dark gray, fissile to slaty; 2-inch bed of *Myalina* shells developed in this zone near Youngstown	1	
61. Coal smut		
60. Clay; varies from 3½ to 4½ feet because of irregular upper surface of underlying Worland limestone; green, may be mottled with red	4	
59. Limestone (top of Worland); one massive bed but upper surface nodular and irregular causing thickness to vary from 3 to 4½ feet; algal in upper part, probably accounting for irregularity; dove-gray, weathers light gray; fossiliferous; large fusulinids, *Squamularia*, large *Ambocoelia*	3	9
58. Shale; green-gray, calcareous, fossiliferous		6
57. Limestone; nodular, fossiliferous		4
56. Shale; green-gray		8
55. Limestone; nodular, fossiliferous		4
54. Shale; green-gray		10
53. Limestone; nodular, fossiliferous		6
52. Shale; green-gray with dark gray zones (zones 52–59 represent Worland limestone; although variable in thickness, upper bed is everywhere massive. Interval from zone 52 to zone 58 composed of green-gray calcareous shale with variable number of nodular limestone beds; it may be shale with subordinate limestone or mostly limestone with interbedded shale; entire interval is highly fossiliferous, containing large fusulinids, *Derbya*, *Ambocoelia*, *Punctospirifer*, *Mesolobus*, crinoid stems and plates)	1	4

	Feet	Inches
51. Coal smut		
50. Clay; green, weathers yellow; nodular limestone in lower $1\frac{1}{2}$ feet	3	1
49. Shale; gray		6
48. Limestone (Tina); medium-gray; lithographic, nodular, earthy		4
47. Shale; dark gray		3
46. Coal smut		
45. Underclay; green above, dark gray below	3	
44. Shale; well bedded below and containing *Chonetes;* upper part tends to be structureless and contains limestone nodules	2	2
43. Shale; gray; lower part has so many *Chonetes* that it is coquina-like; zone of *Chaetetes* in middle	1	2
42. Shale; red above, gray in middle, black at base; prolific clam fauna in red part	1	7
41. Limestone; hard, well jointed, lithographic, purple-gray, weathers light gray; persistent in Adair County; distinctive purple color renders it good key bed; locally there is developed at base of limestone several inches of calcareous conglomerate		$4\frac{1}{2}$
40. Marl (top of Pawnee); weathers yellow to buff; fossiliferous with *Composita*		6
39. Dark fissile shale		6
38. Clay		5
37. Shale; green and silty above, mottled with red below, weathers yellow; blocky	2	8
36. Limestone, small *Mesolobus*		6
35. Shale; green-gray		6
34. Limestone; solid, buff-weathering ledge; fossiliferous; many *Mesolobus* and *Marginifera* with characteristic red type of preservation		7
33. Shale; blue-gray, platy		7
32. Limestone; light gray, earthy, jointed; many *Enteletes* and *Linoproductus*		$6\frac{1}{2}$
31. Marl; calcareous shale and nodular limestone changing locally to impure limestone; highly fossiliferous; *Chonetes*, *Punctospirifer*, *Mesolobus*, *Marginifera*, *Composita*, and *Derbya*	1	
30. Limestone; blue-gray, weathers buff; in 3 or more beds (zones 30–40 are Pawnee limestone)	1	8
29. Shale; light gray above, dark near base	1	4
28. Coal; upper part brown and lignitic (top of Lexington)	1	7
27. Clay		2
26. Coal	1	
25. Clay		3
24. Coal (the "dutchman"); zones 25–28 constitute Lexington coal; absent in some of southeasternmost exposures of Henrietta		2
23. Clay and shale; ash-gray clay above, gray shale below	2	8
22. Limestone (Higginsville); massive; well jointed, weathering into large rectangular blocks; upper surface nodular and irregular; fossiliferous; many *Mesolobus* and large crinoid stems whose white calcite preservations stand out in bold contrast to softer, yellow matrix	3	6
21. Shale; in some places, suggestion of coal smut with thin underclay		6
20. Sandstone; medium- to fine-grained, green when fresh, weathers yellow; massive to bedded; lower part replaced by siltstone in some localities	11	
19. Siltstone and shale; siltstone above, dark gray shale below; weathers drab	8	6
18. Limestone (Houx); weathers brown; gray, earthy; many fossil fragments		4
17. Shale; black, slaty (Summit horizon)	1	4
16. Shale; drab; lower 6 inches, coquina of *Marginifera*, *Mesolobus*, *Linoproductus*, and *Dictyoclostus*		10

	Feet	Inches
15. Shale; dark gray, weathers drab	2	
14. Underclay; lower 2 feet has many limestone nodules which weather and stain it brown	3	6
13. Shale; drab weathering	1	6
12. Limestone (Blackjack Creek); massive, argillaceous, weathers buff		9
Cherokee group		
11. Shale; olive-green with black zones with lenses and nodules of gray phosphatic concretions	2	6
10. Coal (Mulky)		½
9. Underclay; ash-gray	1	6
8. Shale; "dark blue, with limestone concretions"	35	
7. Coal (Bedford); according to Missouri Survey, thin clay parting so characteristic of Bevier coal of Macon County and eastern and central Adair County thickens north and west of Connelsville, Adair County, to several feet of shale and siltstone which splits Bevier coal into "upper bench" and "lower bench;" upper split correlated with Bedford coal of southeastern Livingston County	2	6
6. Clay or sandy shale; supposed equivalent of clay parting in Bevier coal of Macon County	9	
5. Coal ("lower bench" of Bevier)	1	3
4. Underclay	3	
3. Limestone (top of Ardmore)	4	
2. Shale	4	6
1. Limestone (zones 1–3 should be referred to Ardmore limestone)	1	3

Discussion of Section VII

DES MOINES SERIES

CHEROKEE GROUP

Cherokee rocks are below drainage in most of Adair County. Measurements used in the columnar section are from the published record of a shaft and drilling near the Stahl depot (Hinds, 1912, p. 45) but descriptions are supplemented from outcrop studies in Macon County.

Ardmore limestone.—The Ardmore limestone was described by Gordon (1896, pp. 20, 21) as

> an irregular, marly and concretionary limestone underlying the Bevier coal, and separated from it by from 6 to 18 inches of clay. . . . The lower layers are commonly more regularly stratified, while the upper consist, for the most part, of irregular concretionary nodules of limestone imbedded in a marly clay . . . [the limestone] is underlain by from 25 to 30 feet of argillaceous and bituminous shales, sometimes sandy, and with a few thin beds of limestone interstratified.

Because all beds from the lower Ardmore coal to the top of Gordon's Ardmore limestone belong to the same cycle of sedimentation, it seems appropriate to redefine the Ardmore to include all of the limestones (and the intervening shale members) between the coal and the top of the Ardmore of previous definitions. There are several thin fos-

siliferous limestones between the coal and the main massive bed, and one of these, the lower Ardmore "cap rock," is about as persistent as the upper bed.

The Missouri and Kansas geological surveys have traced the Ardmore far toward the southwest, showing it to be equivalent to the Rich Hill limestone of southeastern Kansas and the Verdigris limestone of northeastern Oklahoma. The writer has traced the Ardmore northwestward from the Iowa-Missouri line for 135 miles into Iowa. Throughout this distance it is the best developed limestone in the Cherokee group and it is also the best datum plane, being easy to recognize and constant in lithologic characters.

Lagonda shale.—In western Adair County the Lagonda shale and sandstone (zone 8) attains about the same thickness as in Sullivan County. In Macon County it thins from 50 feet in the west to less than 15 feet near Ardmore in the south-central part of the county. In the NE. $\frac{1}{4}$ of Sec. 13, T. 56 N., R. 15 W., the Mulky and Bevier coals, both well developed, are separated by only $8\frac{1}{2}$ feet of shale.

The Lagonda is remarkable for its sudden changes in lithology, the transition from dark shale and siltstone to soft, friable, micaceous, carbonaceous, cross-bedded sandstone being effected in short distances. The eastward thinning toward the margin of the Forest City basin is probably in part depositional, but there is some evidence of post-Bevier, pre-Mulky erosion in both Macon and Adair counties. At several outcrops near Ardmore sandstone in the Lagonda rests unconformably on the Bevier coal. Hinds (1912, p. 49) cites three localities in Adair County where Lagonda sandstone cuts out at least a portion of the Bevier.

At the type section of the Bevier coal, in Macon County, the coal averages about 52 inches and is consistently divided into two seams by a thin clay parting. In the districts where it is mined in Adair County the coal is about four feet thick and is split into three seams by clay partings. It is the opinion of the Missouri Survey that one of these clay partings thickens to 20 feet northwest of Connelsville to divide the Bevier into an upper "bench" (zone 7) and a lower "bench" (zone 5). In counties to the southwest the upper coal has been called the Bedford.

The Mulky coal is too thin to be mined in Adair County. In southern Macon County it consistently averages $1\frac{1}{2}$ feet. The associated black shale has a distinctive type of lithology that continues far into Iowa. The large size attained by the included disc-like phosphatic concretions is so unique that their presence aids in identification of the Mulky horizon.

HENRIETTA GROUP

Lexington coal.—The Lexington coal thins near its eastern margin of outcrop and is altogether missing in the southeasternmost Henrietta outcrops in Adair County. It has not been recognized in Macon County. In northwestern Adair County the Lexington thickens to about three feet and assumes lithologic characters that continue across Putnam County and into southern Iowa. A typical section is in roadside cutbanks of a north-south road in the NW. $\frac{1}{4}$ of Sec. 11, T. 63 N., R. 17 W., 0.23 mile north of the railroad crossing, where two thin clay partings split the coal into three beds; the middle and upper units are of comparable thickness, whereas the lower one is only two inches. This two-inch band of coal, which persists into Iowa, is known to miners as the "dutchman."

Pawnee limestone.—A comparison of the Ray County section (No. III) with that of Adair County shows several points of difference in the interval between the Exline limestone and the Lexington coal. Some of the changes that take place in the intervening counties are so gradual that, with the aid of two persistent and easily recognizable units, the Worland limestone and the Lexington coal, the interval can be traced without great difficulty. However, poor outcrops greatly hinder the tracing of the Pawnee.

The Henrietta section is so condensed in Adair County and the upper limestone and Myrick Station members of the Pawnee are brought so close together, if indeed they are both present, that no attempt is made to differentiate the Pawnee into members. Beds from zone 30 to zone 36 are thin limestones alternating with fossiliferous shales. This general sequence is persistent but the number and vertical position of the limestone beds is variable. The "Lexington cap rock" (Myrick Station limestone) is considered to be the first prominent limestone bed above the coal in each exposure, but in Adair County the "cap rock" is not everywhere the same bed.

Worland limestone.—In the published works of Hinds (1912), Greene (1914), and Hinds and Greene (1915) the Worland limestone has, almost without exception, been identified as Pawnee in the Adair County sections. The writer's descriptions of the Tina and Worland limestones are primarily from good exposures in Sections 30, 31, and 32, T. 63 N., R. 16 W. Along Missouri State Highway 4 a series of cutbanks in Sections 30 and 31 exposes the interval from the basal Pleasanton sandstone downward to below the Tina limestone. In the NE. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 32, roadside cutbanks expose the interval from the top of the Tina to well below the Higginsville limestone.

The Worland limestone of Adair County is similar, lithologically

and faunally, to the Worland of Sullivan County and can be compared almost zone for zone; zone 59 of Section VII is identical with zone 48 of Section VI; zones 52–58 of Section VII correspond with zones 44–47 of Section VI; zones 50 and 51 of Section VII represent zones 42 and 43 of Section VI.

Exline limestone.—That part of the Henrietta group above the Worland limestone is somewhat thinner than in Sullivan County, there is less coarse clastic material, and the interval between the Exline limestone and the Worland is considerably thinner. Zones 67 (the Exline), 65, and 61 of the Adair County section are correlated with zones 72, 70, and 51, respectively, of the Sullivan County section. The red shale at the base of zone 63 in Section VII is thought to represent zone 53 of Section VI, the coal smut shown as zone 55 in Section VI not being seen in Adair County.

MISSOURI SERIES

PLEASANTON GROUP

Zones 70 to 73 are after Hinds and Greene (1915, p. 87). Zone 70 is doubtless the Ovid coal even though it occupies a somewhat lower position beneath the Hertha than does the Ovid of Sullivan County.

Sandstone is the most conspicuous rock type between the Ovid coal and the base of the Pleasanton. The greatest thickness of sandstone measured at one place is in a roadcut in the NE. $\frac{1}{4}$ of Sec. 22, T. 62 N., R. 16 W., where there are 51 feet of sandstone, the lowest part of the exposed section being 16 feet above the Exline limestone. In the adjacent section 27 Hinds and Greene (1915, p. 87) measured 42 feet of sandstone, the base of which is at the same stratigraphic position. In sections 23 and 26 of this same township, Hinds and Greene (1915, p. 88) questionably identified as the Altamont a limestone near the midportion of the Pleasanton sandstone. This "limestone" seems to be only a local zone of cementation in the massive sandstone, bearing a close resemblance to the huge calcareous concretions that are so common in the several channel sandstones in the Des Moines series of Iowa and which are merely areas within the sandstone that have been firmly cemented by concentrations of calcium carbonate. The "limestone" is not persistent even in Adair County, for Hinds and Greene report conglomerate at this horizon in a near-by outcrop.

The base of the Pleasanton sandstone is normally a few feet above the Exline limestone but in several places in the county it rests on older beds. In the NE. $\frac{1}{4}$ of Sec. 1, T. 62 N., R. 17 W., in the hill south of Billy's Creek, there are 42 feet of sandstone with a thin conglomerate at the base; the base of the sandstone cuts below the Exline and rests

with distinct unconformity on an erosion surface that has a relief of as much as three feet within a few feet horizontally. Across the creek, in the hill to the north, the base of the sandstone rests on beds that are from three to five feet higher stratigraphically. In the vicinity of Novinger, in Secs. 30 and 31, T. 63 N., R. 16 W., the lower 20 feet of the sandstone is exposed in cutbanks along State Highway 4, the base of the sandstone resting $5\frac{1}{2}$ feet above the Exline limestone.

SECTION VIII

T. 65 N., R. 18 W., PUTNAM COUNTY, MISSOURI

Top	*Feet*	*Inches*
Missouri series		
Pleasanton group		
56. Sandstone; about 27 feet exposed; medium- to coarse-grained, soft, mealy, micaceous; locally conglomeratic at base; in some places channeling down to rest on beds below Exline	27	
Des Moines series		
Henrietta group		
55. Shale; weathers drab	4	6
54. Limestone; blue-gray, medium- to coarse-grained, earthy, massive, well jointed, weathers buff and platy; abundant *Trepospira, Sphaerodoma, Schizostoma, Astartella;* one trilobite tail noted (Exline limestone)		8
53. Shale		8
52. Coal		1
51. Underclay; green, with nodular limestone in lower part	2	
50. Gray shale	2	
49. Shale; thin-bedded, blue-gray to green mottled with red, becomes platy below	8	
48. Coal smut		
47. Underclay; green-gray	3	
46. Limestone (top of Worland); blue-gray, weathers light gray; massive; upper surface uneven; fossiliferous, abundant *Squamularia*	2	
45. Shale; green with dark gray to black streaks, calcareous, fossiliferous		8
44. Limestone; fossiliferous		8
43. Shale; green-gray with dark streaks, calcareous, fossiliferous		10
42. Limestone (zones 42–46 comprise Worland limestone)		6
41. Coal smut		
40. Clay; green and red; more or less continuous zone of calcareous nodules in lower foot that imparts buff color to lower part upon weathering	12	
39. Sandstone and shale; lithology variable: may be composed entirely of fine- to medium-grained, micaceous, green sandstone that weathers yellow; may be mostly thin-bedded green and red silty shale becoming platy below; or it may be green sandstone and red silty shale in equal amounts; there is complete and rapid gradation both laterally and vertically between these extremes	10	
38. Shale; red, thin-bedded, and platy	2	
37. Limestone; hard, dense, weathers yellow (top of Coal City = "Water rock")		10
36. Shale; fossiliferous, with many *Derbya* and *Mesolobus*		6
35. Limestone; soft, earthy, fossiliferous, weathers buff (zones 52–54 represent Coal City limestone; all three members are fossiliferous with small *Mesolobus*, large *Chonetes, Derbya*, corals, and crinoid stems)		8
34. Coal smut; at some localities this horizon represented by limonite streak		

	Feet	Inches
33. Shale; upper half red to brown, thin-bedded, platy, lower part blue-gray, thin-bedded, and weathers to very light gray; tendency to weather "white" is characteristic	7	
32. Limestone (Pawnee); massive, jointed, blue-gray, fine-grained, hard, fossiliferous; carries *Mesolobus, Dictyoclostus;* fossils have darker preservation than matrix	1	6
31. Shale and nodular limestone; thin-bedded, calcareous, fossiliferous, green-gray shale, with nodules of dense blue-gray limestone, entire interval weathering buff; fossiliferous; abundant *Derbya, Dictyoclostus, Composita,* and large *Mesolobus; Neospirifer* rare; crinoid stems	6	6
30. Coal; clayey at top	1	10
29. Clay		2
28. Coal	1	3
27. Clay		1
26. Coal ("dutchman"; zones 27–31 inclusive are Lexington coal)		2
25. Underclay; ash-gray and plastic above, darker below and with limestone nodules	5	5
24. Limestone; blue to drab, upper surface uneven; thickness varies from 2 to 6 feet (Higginsville)	3	
23. Shale and sandstone; "whitish at top"	20	
22. Limestone; dark, impure (the Houx)		3
21. Shale; dark and soft at top, black and slaty below	5	6
20. Shale; "dark, calcareous, full of shells"		6
19. Coal (Summit)		2
18. Clay and shale; clay above, shale below	9	
17. Limestone; buff, nodular	1	6
16. Shale; dark where Mulky coal absent	2	
15. Limestone; not everywhere present; weathers buff (zones 15 to 17 are the Blackjack Creek)	1	5
Cherokee group		
14. Shale; dark at top, black and slaty below; contains large concretions	6	
13. Coal (Mulky); absent in many places	1	9
12. Shale and sandstone; "clay at top, sandy shale and sandstone below, black shale at base"	50	
11. Coal; $\frac{1}{4}$-inch clay seam 4 inches from base (Bedford)	2	4
10. Clay	2	
9. Shale and sandstone; sandstone at top, shale below	17	6
8. Coal (Bevier)	1	6
7. Clay	2	3
6. Shale	4	
5. Limestone (the Ardmore)	3	
4. Sandy shale	2	
3. Black shale	8	
2. Light shale	3	
1. Coal (Tebo or lower Ardmore)	1	6

Discussion of Section VIII

The interval between the Worland and Pawnee limestones is so critical that four composite sections have been compiled for the short distance between T. 65 N. in Putnam County, Missouri, and northern Appanoose County, Iowa. Near the Iowa-Missouri line this interval thickens and undergoes some lithologic changes, so two composite sections were compiled for Putnam County, one (Section VIII) in T. 65 N., R. 18 W., the other (Section IX) in T. 67 N., R. 18 W. Because the correlation of the Iowa-Missouri sections is the main object of the

traverse, another generalized section (Section X) has been constructed for an area just across the line in Iowa, but in the same township as Section IX.

Zones 25–56 of Section VIII were measured in T. 65 N., R. 18 W., and the descriptions are chiefly from three exposures: (1) roadcut in the NW. ¼ of Sec. 27, in the hill south of the creek; (2) roadcuts along the northeast-southwest road in the hill west of the creek, near the center of the east line of the NE. ¼ of Sec. 28; (3) and in a W. P. A. quarry on the north side of the creek, in the N. ½ of Sec. 20.

Zones 8–24 are after Hinds' (1912, p. 330) generalized section for the outcropping beds of Putnam County, so it applies equally well to the section for northern Putnam County (Section IX). Zones 1–7 are from the record of a drilling ¼ mile south of the Mendota station (Hinds, 1912, p. 338).

DES MOINES SERIES

CHEROKEE GROUP

The Mulky coal occurs sporadically but the overlying dark shale with the lenses and nodules of gray concretions is persistent.

Except for a slight increase in thickness, the Lagonda shale and sandstone interval is comparable to that of Adair County. There are two coals in the lower half of the section. Concerning their correlation Hinds (1912, p. 332) says, "these beds are probably the equivalents of the two benches of the Bevier in Adair County, but until this is proven, the higher will be designated the Bedford and the lower the Bevier." There seems to be little doubt that they are the same as the two coals in northwestern Adair County that have been called upper and lower Bevier, but the continued use of the terms Bedford and Bevier is favored until it has been definitely established that the upper coal is a split from the lower one.

HENRIETTA GROUP

Coal City limestone.—As much as 2 feet of argillaceous buff-weathering limestone, the Coal City, locally termed the "Water rock" (zones 35–37), is developed in Putman County. It lies several feet below the underclay of the Worland cyclothem and is separated from the underlying Pawnee limestone by several feet of shales containing a thin carbonaceous streak. The Missouri Survey (Grohskopf, Hinchey, and Greene, 1939, p. 19) now believes the Coal City is probably Pawnee, although it was not so correlated in their earlier reports.

On the basis of stratigraphic position the Coal City limestone would appear to correlate with the upper limestone member of the Pawnee of west-central Missouri. If the Livingston, Sullivan, and

Adair counties sections could be ignored the writer would not hesitate to make this correlation, but in these counties the thinning of the shale members brings the limestones so close together that the writer has not been able to differentiate the two limestone members of the Pawnee. The greatest condensation takes place in Adair County. Northward in Putman County the shales begin to thicken again. For the "Water rock" the name Coal City is chosen from good outcrops in southeastern Appanoose County, Iowa.

Altamont limestone.—Between Adair and Putman counties the Worland limestone changes somewhat, but the massive irregular bed at the top, followed below by green, calcareous, fossiliferous shale and nodular limestone, makes the formation easy to recognize.

The Tina cyclothem apparently disappears as the Adair-Putnam county line is approached, for it was not found in Putnam County. This cyclothem is present northwest of Novinger, Adair County, but there it is considerably thinner and more nodular than in the southwestern part of the same county. The failure of the Tina cyclothem to appear in Putnam County sections with the simultaneous thickening of the underclay of the Worland cyclothem does not seem to be a mere matter of chance. It is possible that the thick Worland underclay of Putnam County is the time equivalent of all of the Tina cyclothem plus the Worland underclay of the area on the southwest. On the contrary, the possibility should not be overlooked that the Tina cyclothem was once present in Putnam County but was obliterated by the processes that formed the Worland underclay.

That part of the Henrietta group above the Worland limestone is so much like the Adair County section that little comparison is necessary. The Exline limestone was correlated with the "Floating rock" (Cooper Creek of this report) of Appanoose County, Iowa, by the Missouri Survey. It will be shown in Section X that the two limestones are separated by a shale and clay interval in which there is a coal (zone 52 of Section VIII).

MISSOURI SERIES

PLEASANTON GROUP

Uppermost Pleasanton is absent in Richland township but the lower part is represented by a variable amount of soft, yellow-brown, micaceous sandstone, whose thickness depends on the amount of preglacial erosion. Like its equivalent in Adair County (Section VII, zone 69), the sandstone rests with distinct unconformity on the underlying beds. The base of the sandstone is normally a few feet above the Exline limestone but in some places within this township it cuts through

this zone. Hinds and Greene (1915, p. 87) report 20 feet of coarse-grained sandstone with conglomerate at its base at a locality south of Rosewood. They report conglomerate resting on Cherokee beds near Mapleton, in eastern Putnam County, and across the river in Schuyler County, indicating the erosion of 100 feet of Henrietta and upper Cherokee strata. The Putnam County conglomerate has long been correlated with the Chariton conglomerate of Appanoose County, Iowa (Hinds, 1912; Greene, 1914; Hinds and Greene, 1915). Hinds and Greene correctly placed the stratigraphic position of this important unconformity as just above the Exline limestone, but the top of the Henrietta was drawn at the top of what they called Pawnee limestone (the Worland). Grohskopf, Hinchey, and Greene (1939, p. 22) are still of the opinion that a more important stratigraphic break lies between the Exline and Worland limestones, "possibly explaining some of the irregularities found in this interval." It is the observation of the writer that beyond the substitution of green sandstone for red shale, and *vice versa*, which seems to be a normal change and one that can be expected in Pennsylvanian rocks of Iowa and Missouri, this interval is remarkably regular. The existence of an important stratigraphic break between the Worland and Exline limestones in north-central Missouri is doubted.

SECTION IX

T. 67 N., R. 18 W., PUTNAM COUNTY, MISSOURI

Top	*Feet*	*Inches*
Des Moines series		
Henrietta group		
24. Limestone; weathered remnant of massive upper member of Worland	2	
23. Covered; probably mostly variegated green and red clay	9	6
22. Sandstone; maximum observed thickness of 9 feet; fine- to medium-grained, soft, micaceous, green, weathers yellow; upper 5 feet replaced laterally by variegated green and red clay	9	
21. Shale; weathers drab	2	
20. Red shale; zone 21 and upper part of zone 20 may be replaced laterally by green sandstone	4	6
19. Limestone (Coal City); not well exposed, in two beds, weathers buff	2	
18. Shale; blue-gray above, weathering "white"; dark gray, almost black below	6	
17. Carbonaceous streak		
16. Clay; stained brown by limonite; many selenite crystals	1	
15. Shale; weathers buff; calcareous and fossiliferous with *Derbya*, *Linoproductus*, and *Dictyoclostus*	3	6
14. Limestone (Pawnee); dense, blue-gray, weathers buff		6
13. Shale; with discontinuous zones of nodular, dense, blue-gray limestone; calcareous, fossiliferous, weathers yellow	2	4
12. Limestone, like zone 14		6
11. Shale; gray, weathers drab, lower 6 inches black and slaty	3	
10. Coal (top of Lexington)	1	8
9. Ash-gray clay		1½
8. Coal	1	10

	Feet	Inches
7. Clay		2
6. Coal ("dutchman"; zones 6–10 are Lexington coal)		2
5. Underclay; dark gray above, ash-gray below and stained yellow with ferric sulphate	1	6
4. Covered	3	
3. Limestone (Higginsville); massive, weathers buff; $2\frac{1}{2}$–3 feet	2	9
2. Shale; weathers "white"	2	6
1. Siltstone and sandstone	4	6

Discussion of Section IX

Section IX is a composite of three exposures in Lincoln Township, T. 67 N., R. 18 W., only two townships north of the area represented by Section VIII: (1) exposures in road cuts in the hill west of the bridge and west of the road intersection in the SE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 34; (2) cutbanks in an east-west road near the top of the hill in the NE. cor. of Sec. 25 and near a turn in the road; and (3) an exposure in the E. $\frac{1}{2}$, SW. $\frac{1}{4}$ of Sec. 36.

The only appreciable difference between this section and the same interval in Section VIII is in the beds between the Coal City limestone and the Pawnee limestone which contains the blue-gray shale that so characteristically weathers "white." The shale is slightly thicker than in T. 65 N. and near its middle there is a thin carbonaceous streak that was not observed in Section VIII.

SECTION X

T. 67 N., Appanoose County, Iowa

Top	*Feet*	*Inches*
Missouri series		
Pleasanton group		
39. Shale; silty, gray to drab, weathers yellow; scattered clay-ironstone concretions; overlain by glacial drift in which there are a few large slabs of Hertha limestone; base of Pleasanton probably somewhere within body of shale	24	
Des Moines series		
Henrietta group		
38. Limestone (Exline); upper 3 inches laminated, lower 1 foot massive; dark blue-gray, earthy, medium-grained; well jointed, weathers brown and slabby; fossiliferous with *Chonetes* and white crinoid stems which contrast strongly with weathered yellow-brown matrix	1	3
37. Shale; poorly exposed; drab		6
36. Coal smut		
35. Underclay; ash-gray and plastic above, dark gray below and with much nodular limestone in lower 1 foot	2	11
34. Limestone (Cooper Creek); admixed with green clay; light gray; fragmental, nodular limestone; algal; a few large *Ambocoelia*	1	9
33. Clay; green above, red below; some nodular limestone in lower part	5	5
32. Shale and siltstone; green mottled with red, becoming red below; predominantly shale	10	
31. Covered	10	
30. Limestone (top of Worland); blue-gray, weathers light gray; wavy bedding, but more or less massive upon weathering; upper surface irregular, nodular, algal; fossiliferous	3	

	Feet	Inches
29. Shale; green-gray, fossiliferous		4
28. Limestone; wavy-bedded, like zone 30 but not so massive	2	8
27. Shale; green, dark zone near middle with some small ash-gray phosphatic concretions; fossiliferous; *Chonetes*, *Mesolobus*, *Derbya*, and *Ambocoelia*		7
26. Limestone; nodular; fossiliferous with *Mesolobus* and *Ambocoelia;* 0–4 inches		2
25. Carbonaceous seam		1
24. Underclay; upper foot ash-gray; main body mottled green, yellow, and red	5	10
23. Covered; logged as shale in section which Bain (1896, p. 391) gives for Albert shaft at Cincinnati	7	
22. Sandstone; green, weathers buff; fine- to medium-grained, bedded, soft, micaceous	5	6
21. Covered; record of interval obtained from Albert shaft	3	6
20. Limestone (Coal City); light blue-gray, hard, finely crystalline; in two massive beds; weathers buff; fossiliferous; *Chaetetes*, fusulinids, and brachiopods abundant; locally very large crinoid stems are so abundant as to form coquina	1	10
19. Shale; gray, calcareous, poorly bedded; fossiliferous		3
18. Carbonaceous streak		
17. Clay; light blue-gray		1
16. Shale; green-gray, soft, obscurely bedded, clayey		9
15. Shale; dark blue-gray, thinly and evenly laminated, with yellow-brown stains in upper 2 feet; selenite crystals scattered through lower few inches	4	3
14. Shale; yellow to reddish brown, hard, impregnated with selenite crystals	1	3
13. Limestone (top of Pawnee); hard, nodular, earthy, light gray; large productids abundant; 1–9 inches		4½
12. Shale; green-gray above, brown to black below; evenly bedded, fossiliferous; *Chonetes* and ostracods abundant	1	
11. Limestone; finely crystalline, dense, earthy, blue-gray, a few fossils	1	8
10. Shale; gray to brown, thinly laminated, blocky fracture, finely micaceous, calcareous, scattered selenite crystals; *Chonetes* abundant, 1¾–2¼ feet	2	
9. Siltstone; gray, calcareous, weathers buff, brachiopod fragments abundant; 0–5 inches		2½
8. Shale; black, slaty; weathers to thin hard sheets; lenses, bands, and small almond-shaped phosphatic concretions; orbiculoid brachiopods abundant along some bedding planes	1	6
7. Coal; bright; cubical cleavage; few thin shale streaks (top of Mystic)	1	9
6. Clay; fragments of carbonized wood		3
5. Coal	1	2
4. Marcasite; thin, irregular band		1
3. Coal (zones 3–7 represent Mystic coal)		3
2. Underclay; green-gray above, lower one-third rusty; abundant root marks, slickensided	2	6
1. Limestone; massive, fine-grained, earthy, gray, weathers buff; brachiopods abundant (Higginsville)	1	2

Discussion of Section X

Section X is a composite of several exposures in T. 67 N., in southern Appanoose County, Iowa. None of the outcrops is more than three miles north of the state line. The Pleasanton shale was measured in the SE. ¼ of Sec. 6, in R. 17 W., in gullies on the south side of a small west-flowing creek. The Exline limestone and the Cooper

Creek limestone were studied at this locality and at several places upstream along this creek. The Worland limestone was studied in the SW. ¼ of Sec. 6, and in cutbanks in a north-south road 0.4 mile south of the NE. cor. of Sec. 12, R. 18 W.

Beds between the Worland and Exline limestones are only partly exposed at both of the aforementioned localities, the thickness of the interval being obtained from the published record of the Albert shaft at Cincinnati.

Strata between the Exline and Higginsville limestones are well exposed in cutbanks in the east-west road in the hill just east of the road corner in the SW. ¼ of Sec. 16, R. 16 W.

DES MOINES SERIES

HENRIETTA GROUP

Mystic coal and associated beds.—The "Mystic bottom-rock" (Higginsville limestone) is, of course, identical with the "Lexington bottom-rock" since it has long been known that the Mystic coal of Iowa is the same as the Lexington of Missouri (Keyes, 1894, p. 409). As in Missouri, the "Mystic cap rock" (a part of the Pawnee limestone) is not everywhere the same limestone but may be any one of several dense blue-gray limestones in the overlying shale.

Coal City limestone.—For Bain's "Seventeen-foot limestone" the geographic name Coal City limestone is proposed. The type section is in the east bluff of Chariton River in the SE. ¼ of Sec. 16, T. 67 N., R. 16 W., near Coal City in southeastern Appanoose County. A good exposure is in road cuts of the east-west road in the hill just east of the bridge over the Chariton. Here the base of the limestone is about 12 feet above the top of the Mystic coal. The limestone crops out at a number of places in the county. There are excellent exposures near Brazil, northwest of Centerville.

The Coal City is identical with the "Water rock" of Putnam County, Missouri, occurring in two massive buff-weathering beds as in Section IX, and being about the same thickness. In Township 67 North this limestone is fossiliferous with *Chaetetes* and fusulinids in addition to the brachiopod fauna that characterizes this horizon in T. 65 N., R. 18 W., in Missouri.

The coal smut shown as zone 18 is probably to be correlated with zone 34 of Section VIII and zone 17 of Section IX.

Worland limestone.—The Worland limestone is much the same as in Missouri, carrying an identical fauna. However, it contains more limestone and less shale in Appanoose County than in Putnam County.

Cooper Creek limestone.—For Bain's "Floating rock" the name Cooper Creek is proposed for good outcrops along tributary ravines of Cooper Creek in the vicinity of Centerville in Appanoose County. There are good outcrops of this limestone in some west-side tributary ravines of Cooper Creek, in pastures north of Iowa Highway 3, in the SE. ¼ of Sec. 26, T. 69 N., R. 18 W. The Cooper Creek is not well developed in Putnam County, Missouri, and if present in T. 65 N. it is represented only by the nodular limestone developed in the lower part of the underclay shown as zone 51 of Section VIII.

In the lower part of zone 35 there are a few scattered calcareous nodules which become increasingly prominent downward and form a well defined and persistent ledge of nodular, fragmental, algal limestone, which is the southern extension and featheredge of Bain's "Floating rock." The writer is at a loss to know the significance of this nodular limestone. It occupies the position in the cyclothem of a fresh-water limestone, being developed in the base of an underclay. Genetically the uppermost part seems to be identical with the irregular nodules of dense, blue-gray, unfossiliferous limestone that commonly are developed in the lower part of Pennsylvanian underclays in the area covered by this report, but in the exposures in Sec. 6, T. 67 N., R. 17 W., there is complete gradation downward of this phase into a nodular algal limestone that carries a few large *Ambocoelia*. A few miles to the north, in the vicinity of Centerville, the limestone thickens to a prominent ledge, and although it retains its fragmental, nodular character throughout, the upper portion is more nodular and seems to represent the algal or receding marine phase of a cycle, whereas the lower part is typically marine, carrying abundant brachiopods and fusulinids.

The interval between the Cooper Creek and Worland limestones exceeds by more than 10 feet the thickness of the equivalent interval in Section VIII.

Exline limestone.—The type locality of the Exline limestone is about 1½ miles south of the southwest corner of Exline, Appanoose County. The limestone is well exposed in a west-flowing tributary ravine of North Shoal Creek, in the SE. ¼ of Sec. 6, T. 67 N., R. 17 W. Along this ravine the exposed section includes the Worland, Cooper Creek, and Exline limestones and shale almost up to the horizon of the Hertha limestone.

The Exline limestone is the direct lateral equivalent of the *Trepospira* zone of northern Missouri. In Iowa the limestone gradually becomes more typically marine, a brachiopod fauna replacing the molluscan fauna of the earthy impure limestone of farther south. The

Exline has been overlooked by previous Iowa workers but recent work shows it to extend as far northwest as Dallas County.

Zones 35, 36, and 37 of this section are correlated with zones 51, 52, and 53 of Section VIII.

Younger Henrietta beds.—Formations younger than the Worland limestone are not represented in Section IX in northern Putnam County, Missouri, thereby making it necessary to compare zones 31–38 with the Adair County section.

MISSOURI SERIES

PLEASANTON GROUP

The Des Moines-Missouri boundary probably lies somewhere within the drab silty shale of zone 39 but there is no well defined stratigraphic break.

SECTION XI

Central and Northern Appanoose County, Iowa

Top	*Feet*	*Inches*
Missouri series		
Kansas City group		
63. Limestone (Hertha); one massive ledge of hard, gray, finely crystalline limestone with veinlets of coarsely crystalline calcite; weathers yellow; fossiliferous; brachiopods and crinoid stems....	2	6
Pleasanton group		
62. Shale; even-bedded, green-gray, calcareous, fossiliferous, weathers yellow above and brownish gray below..................	5	6
61. Coal (Ovid?)...		5
60. Clay; ash-gray in upper 5 inches, blue-gray below and slightly silty..	5	7
59. Shale; green-gray; becomes drab upon exposure; massively bedded, blocky fracture, micaceous, silty....................	27	7
58. Limestone (Exline); massive ledge of dense, fine-grained, blue-gray, earthy limestone, weathering yellow to brown............		8
57. Coal smut		
56. Underclay; ash-gray, highly plastic when wet.................	2	
55. Limestone (top of Cooper Creek); one massive bed of nodular, fragmental, algal limestone; irregular nodules of dark gray, dense lithographic material in light gray, finely crystalline matrix; matrix is less resistant to weathering, so that weathered surface appears conglomeratic; fossiliferous with *Squamularia* and fusulinids..	4	
54. Shale; with many small nodules of limestone; fusulinids exceedingly abundant (zones 54 and 55 constitute Cooper Creek limestone)..	1	6
53. Coal streak		
52. Clay and shale; poorly exposed, red and green, weathers to red soil; ratio of clay to shale unknown.......................	7	6
51. Shale; green-gray, thinly bedded, platy; calcareous nodules distributed along joint planes..............................	9	
50. Coal streak; persistent		
49. Clay; nodules of limestone at base.........................	1	
48. Shale; green, weathers yellow; even massive beds...........	2	6
47. Limestone (top of Worland); hard, dense, gray limestone, weathers yellow; some areas appear pseudo-oölitic; massive; upper surface irregular; algal phase of cyclothem; worm borings and mollusks in upper part..............................	2	2

	Feet	Inches
46. Shale; many calcareous algal pellets; fossiliferous, large crinoid stems abundant		10
45. Limestone; blue-gray, weathers light gray; more or less massive but upon weathering may be seen to be wavy-bedded; fossiliferous; large fusulinids characteristic	2	4
44. Shale; green-gray, calcareous, fossiliferous; *Marginifera* abundant		3
43. Limestone; like zone 45; dove-gray, with green argillaceous splotches	2	2
42. Shale; green-gray, thinly and evenly bedded, fossiliferous with abundant *Ambocoelia, Derbya, Composita,* Bryozoa, and a few *Mesolobus*	2	
41. Coal smut		1
40. Clay; blue-gray above, red below	10	
39. Shale; replaced laterally by green sandstone	7	6
38. Shale; green mottled with red; weathers to red soil; soft, soapy, thin-bedded, lower part platy	9	
37. Shale; green, platy	1	6
36. Limestone (Coal City); blue-gray; hard, finely crystalline, thin-bedded to massive, weathers buff; fossiliferous; *Chaetetes,* small *Mesolobus,* fusulinids, abundant large crinoid stems	2	6
35. Shale, green-gray, weathers yellowish, fossiliferous		6
34. Coal smut		1
33. Clay; gray, rusty along joints	1	8
32. Shale; dark blue-gray with red mottling in upper 2 feet, weathers "white;" selenite crystals and iron stains abundant	4	4
31. Shale; gray, with two black carbonaceous streaks		7
30. Gray shale	1	
29. Shale and nodular limestone (top of Pawnee); weathers buff; very fossiliferous with *Neospirifer, Derbya, Composita,* and *Dictyoclostus*	2	
28. Gray shale	1	
27. Limestone; massive, well jointed, dense, fine-grained, blue-gray, weathers buff	2	
26. Black slaty shale	2	6
25. Coal (top of Mystic)	1	8
24. Clay parting		2½
23. Coal		9
22. Clay parting		½
21. Coal (zones 21–25 are Mystic coal)		2½
20. Underclay; ash-gray	1	
19. Limestone (Higginsville); medium gray, finely crystalline, very hard, weathers buff; irregular upper surface; sparingly fossiliferous with large crinoid stems, *Mesolobus, Neospirifer, Composita, Derbya,* and productids	2	
18. Carbonaceous zone; soft black shale and coal in four thin streaks separated by one-half inch clay partings		4
17. Clay; green-gray, soft, plastic, finely micaceous, evenly and thinly bedded, weathers brown	1	6
16. Shale; gray, weathers drab	3	
15. Shale; green mottled with brownish red, soft, evenly bedded, blocky fracture, micaceous, silty	7	
14. Shale; blue-gray; lower 1 foot soft, limy, contains many fossil fragments	4	
13. Limestone (Houx); dark gray, earthy, weathers brown, with masses of lighter gray coquina; weathers into square or rhombohedral blocks; abundant glauconite and finely crystalline aggregates of pyrite; a few vertical joints filled with calcite; very fossiliferous with large crinoid stems, Bryozoa, abundant *Mesolobus* and *Chonetes,* and *Composita*		8
12. Siltstone; light gray, soft, clayey, poorly bedded, calcareous, with shell fragments		6

	Feet	Inches
11. Shale; black, massively bedded and blocky in upper 1 foot, slaty and canneloid below with abundant gray phosphatic concretions; lower 2 feet resistant to weathering	3	
10. Dark shaly limestone; impure earthy limestone locally changing to shale; fossiliferous with *Marginifera* and *Mesolobus*		4
9. Underclay; ash-gray, soft, plastic, massive, with orange and brown stains along joints; vertical root impressions; calcareous nodules in lower part	3	6
8. Shale or clay; badly slumped, gray and structureless; may be weathered shale	1	5
7. Limestone (Blackjack Creek); light blue-gray, hard, fine-grained, jointed so as to weather into large massive buff-colored blocks; sparingly fossiliferous	1	
Cherokee group		
6. Covered	2	6
5. Green shale		5
4. Coal smut (Mulky horizon)		
3. Clay; gray, calcareous nodules in lower part	4	6
2. Shale; red, bedded, with blocky fracture	3	6
1. Shale; green-gray, weathers drab, thin-bedded, blocky fracture, soft, micaceous, silty; 8 feet exposed	8	

Discussion of Section XI

North of T. 67 N. there is but one locality in Appanoose County where the Hertha limestone has been seen. In the vicinity of Centerville beds ranging in age from the Hertha to below the Worland limestone are exposed. The interval from the Hertha to about the middle of zone 59 was measured in the clay pit in the western edge of Centerville, in the SW. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 36, T. 69 N., R. 18 W. Beds from the middle of zone 59 to the top of zone 52 are described from outcrops a short distance northwest of the clay pit, in cutbanks along a small east-flowing tributary of Cooper Creek, in the east part of the SW. $\frac{1}{4}$ of Sec. 26, T. 69 N., R. 18 W., supplemented by descriptions of exposures in a parallel ravine $\frac{1}{8}$ mile south, and by exposures in road cuts of Iowa State Highway 3 and in the pasture just south of the highway.

Distances between the Hertha, Cooper Creek, and Worland limestones were obtained by hand-level measurements of exposures in and near the northeast-southwest road in the hill south of the brick pit.

Descriptions of beds between the Cooper Creek and the Worland limestones are from a road-cut exposure in the NW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 1, T. 69 N., R. 18 W., between Darbyville and Rathbun. The description of the Worland limestone is from an exposure in a small quarry south of State Highway 3, about 200 yards southwest of the Chicago, Burlington, and Quincy Railroad crossing.

Descriptions of the beds between the Worland limestone and the Coal City limestone are from outcrops along Walnut Creek, southwest of County Highway D, in the NW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 16, T. 69 N., R. 18 W., and in the south-central portion of the NE. $\frac{1}{4}$ of Sec. 19 of the

township in a road cut near the Chicago, Burlington, and Quincy underpass, in addition to the exposures mentioned in the last paragraph. These exposures are supplemented by the published log (Bain, 1896, p. 379) of a boring in the NE. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 19, T. 69 N., R. 17 W.

The section from the Coal City limestone to the Higginsville limestone is generalized from two exposures; one near the underpass in the NE. $\frac{1}{4}$ of Sec. 19, T. 69 N., R. 18 W., and the other in cutbanks of Walnut Creek in the NE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of the same section. Descriptions of beds below the Higginsville limestone are from outcrops along the creek in the NW. $\frac{1}{4}$ of Sec. 1, T. 70 N., R. 17 W., and in the first main tributary gully that flows in from the east.

DES MOINES SERIES

HENRIETTA GROUP

The Cooper Creek limestone (zones 54 and 55) thickens northward from Section X to become a prominent ledge in central and northern Appanoose County and a thin coal streak (zone 53) is developed just beneath it. Green and red mottled shale continues to characterize the interval between the Cooper Creek and the Worland limestones.

From top to bottom the sequence between the Worland and Coal City limestones contains a thin coal streak, a thick variegated underclay, and green and red mottled shale that is replaced laterally by fine-grained green sandstone. This lithologic succession is typical of sections farther south but the over-all thickness of the interval is greater than it is in southern Appanoose and northern Putnam counties.

Just below the Coal City limestone there is a coal smut that is correlative with zone 18 of Section X; the dark, blue-gray shale between this coal and the Pawnee limestone continues to weather "white."

The succession of beds adjacent to the Mystic coal is much the same as in Sections VII, VIII, IX, and X, but in northern Appanoose County a carbonaceous seam and an associated underclay take their place in the section beneath the Higginsville limestone.

Zone 13, the Houx limestone, and the underlying black slaty shale (the Summit) with the fossiliferous zone at the base continue to form a succession that is easy to identify.

MISSOURI SERIES

PLEASANTON GROUP

There are two noticeable changes in the Pleasanton group over the exposures in Sullivan and Adair counties, Missouri: the interval is much thinner, and there is less coarse clastic material.

The Chariton conglomerate of Bain (1896, p. 394) probably marks the base of the Missouri series but it crops out at only two places within the county and under such conditions as to make it impossible to determine its exact stratigraphic position. It is definitely younger than the Coal City limestone and there seems to be no question but that it is Pennsylvanian, but beyond that nothing seems to be certain. Hinds and Greene (1915, pp. 87, 94) have described similar conglomerate in Putnam and Schuyler counties, Missouri, and on the basis of lithologic similarity have correlated it with the Chariton. At a locality west of Truro in southeastern Madison County a conglomerate of almost identical lithology lies stratigraphically between the Hertha and Exline limestones and is therefore the approximate equivalent of the Putnam County, Missouri, conglomerate. On these indirect, and admittedly incomplete, bits of evidence the Chariton conglomerate is tentatively assigned a place between the Hertha and Exline limestones.

KANSAS CITY GROUP

Identification of zone 63 as the Hertha limestone has an important bearing on the correlation of Bain's "Appanoose formation." The Hertha has not heretofore been recognized in Appanoose County. The limestone has been seen at only one locality within the county, that in the clay pit at the west edge of Centerville, in the SW. ¼, NW. ¼ of Sec. 36, T. 69 N., R. 18 W.

SUMMARY

This traverse has yielded the following stratigraphic information.

1. Recognition of the Hertha limestone in Appanoose County, Iowa, has an important bearing on the correlation of Bain's "Appanoose beds."
2. Widespread channel sandstone in the lower Pleasanton (of former reports) marks the most important stratigraphic break between the Hertha and Worland limestones. The surface of unconformity is normally a few feet above the Exline limestone but at several places in Livingston, Grundy, Sullivan, Adair, and Putnam counties, Missouri, it cuts through the Exline and rests with distinct unconformity on older formations.
3. The long accepted correlation of the Chariton conglomerate of Appanoose County, Iowa, with a lower Pleasanton conglomerate of Putnam County, Missouri, is strengthened by several bits of rather indirect evidence. The Chariton conglomerate probably marks the base of the Missouri group in Iowa.
4. There is a noticeable thinning of the Pleasanton from the Kansas City area to the Iowa line, accompanied by a relative decrease

in the amount of sandstone. This change is most pronounced north of Adair County, Missouri. There is such rapid vertical and lateral variation in lithology that individual units are hard to trace for any considerable distance.

5. The Exline limestone (the *Trepospira* zone of Hinds and Greene) was traced as far south as Chillicothe, Livingston County, Missouri. It is recorded in Iowa for the first time. Variation from an argillaceous limestone in north-central Missouri to a more pure limestone in Iowa is accompanied by marked faunal changes.

6. The name Cooper Creek limestone is proposed for the "Floating rock" of Bain's Appanoose County report. This algal limestone, a prominent ledge near Centerville, thins near the Iowa-Missouri line. In Putnam County the featheredge of this limestone is a zone of calcareous nodules in the underclay of the Exline cyclothem.

7. The Worland limestone of Greene is a member of the Altamont limestone. It has repeatedly been called Pawnee in older reports; Marbut's description of the Henrietta group at Lexington includes the Worland. It is correlated with the "Fifty-foot limestone" of Iowa.

8. The name Tina is proposed for the lower limestone member of the Altamont.

9. The Tina limestone persists as far north as Novinger, Adair County, Missouri, but it fails near the Adair-Putnam county line with the simultaneous thickening of the underclay of the Worland cyclothem above.

10. North of Lafayette County there is such complete gradation between the upper limestone and Myrick Station limestone members of the Pawnee that they are difficult to separate.

11. Poor outcrops, a general eastward thinning of the Henrietta, changes in lithology, and an unconformity below the Worland limestone all combine to interfere with the northeastward tracing of the Pawnee.

12. For Bain's "Seventeen-foot limestone" the term Coal City limestone is proposed. The Coal City is equivalent to the "Water rock" of Putnam County, Missouri.

13. The term Myrick Station limestone is substituted for "Lexington cap rock." As the massive limestone is traced north of the Missouri River it dissipates into calcareous shale with discontinuous stringers of limestone. The "Lexington cap rock" (of miners) of north-central Missouri (the "Mystic cap rock" of Iowa) is the first prominent limestone bed above the coal.

14. The "upper Fort Scott limestone," "Rhomboidal limestone," and "lower Fort Scott limestone" members of the Fort Scott limestone

formation are named, in respective order: Higginsville limestone, Houx limestone, and Blackjack Creek limestone. The Houx and Blackjack Creek are recognized in Iowa for the first time.

15. The basal sandstone of the Blackjack Creek cyclothem is unconformable on underlying beds in many places. Locally, channel sandstones (the "Squirrel") cut out all beds between the Mulky coal and Ardmore limestone.

16. The Ardmore is the most important limestone in the Cherokee group. Despite its thinness the limestone has remarkable distribution, extending from the vicinity of Tulsa, Oklahoma (the Verdigris limestone), to Guthrie County, Iowa (the "Two-layer limestone"). Throughout this area it is a valuable marker in an interval where persistent and diagnostic units are generally lacking.

WORKS TO WHICH REFERENCE IS MADE

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL 25, NO. 1 (JANUARY, 1941) PP. 73-103, 1 FIG.

POSITION OF SAN ANDRES GROUP WEST TEXAS AND NEW MEXICO[1]

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Midland, Texas

ABSTRACT

Stereograms were made of a wide area of the South Permian basin to gain a regional perspective of the upper Permian stratigraphy. Recognized as major structural features are the Val Verde basin, Fort Lancaster platform, Blackstone arch, Cerf basin, San Simon syncline, and Halfway syncline. Structural features were controlling factors in Permian deposition and the stratigraphic phenomena of the Permian basin are related directly to lateral gradation. Surface studies and subsurface work reveal that, as a result of this gradation, many of the various facies are time equivalents. Unconformities are recognized as the best time markers because of the changing facies. Surface trace reveals that several hundred feet of Word clastics grade into the Vidrio limestone in the northeastern Glass Mountains. Consequently the Vidrio is recognized as the upper division of the Word and the Capitan formation is restricted to the reef facies of the Gilliam to conform with its usage in the Guadalupe Mountains. It is proposed to place the base of the Word at a conglomerate about 300 feet below the present base of the formation. In the Glass Mountains, evidence suggests the pre-Whitehorse unconformity at the base of the Gilliam, and the unconformity at the base of the Word is believed to be equivalent to the unconformity at the base of the El Reno. The San Andres group is believed by the writer to be the time equivalent of the Word formation, the lower two divisions of the Delaware Mountain group, and the El Reno group, each of which is separable into an upper and lower division over a wide area in the South Permian basin. These correlations are supplemented by paleontologic information which shows that preponderance of evidence is accumulating that the San Andres group should be placed in the Guadalupe series instead of the Leonard series.

EDITORIAL INTRODUCTION

E. Russell Lloyd
Midland, Texas

The stratigraphic position of the San Andres formation or group is one of the important problems confronting students of the West Texas and New Mexico Permian. Authors of recent papers have tentatively correlated the San Andres with the Bone Spring formation, thereby putting it in the Leonard series. Lewis, in the present paper, offers a strong argument that the San Andres should be correlated with the lower and middle subdivisions of the Delaware Mountain group of the Delaware basin and with the Word formation of the Glass Mountains, thereby putting it in the Guadalupe series.

The great difficulty, as pointed out by Lewis, is in making correlations between the "Platform" and "Basin" areas with their contrasting rock facies. Many geologists agree with Lewis' correlations while others disagree. Much

[1] Read before the mid-year meeting of the Association at El Paso, Texas, September 30, 1938, and before the West Texas Geological Society at Midland, August 17, 1940. Manuscript received, August 31, 1940.

The stereograms referred to in the text may be obtained on blue-line paper prints in 3 sheets approximately 72×42 inches, 48×40 inches, and 32×20 inches, respectively (vertical scale, 1 inch=1,000 feet). Price, per set of 3, in roll, postpaid: to A.A.P.G. members and associates, colleges, and public libraries, $3.35; to others, $4.25. Write to Association headquarters, Box 979, Tulsa, Oklahoma.

[2] Consulting geologist, Box 746.

detailed study will be necessary involving all lines of evidence before the problem will be solved to the satisfaction of all interested geologists.

Lewis makes reference to numerous individual wells. The sections and correlations for most of these wells are shown in the stereograms to which reference is made in the text. These stereograms have not been published but copies can be obtained from Association headquarters.[3]

INTRODUCTION

In the fall of 1937 the writer began a subsurface study of the Whitehorse group which lies between the San Andres group and the main salt body in the South Permian basin. A stereogram was made of a rather restricted area of the south and east end of the Midland basin and the group was divided into five formations. Certain facts were also found suggesting the correlation of the San Andres with formations on the south and west sides of the Permian basin.

A discussion of the Permian stratigraphy of Oklahoma and Kansas appeared in December, 1937.[4] From this symposium it was seen that the problems of the Anadarko basin were similar to those of the South Permian basin and that the Anadarko basin was closely related to the larger basin on the south. It was decided, since the problems of the Permian basin were regional ones, that a clearer conception could be gained by study of a larger area.

Since the use of stereograms is considered a much better approach to the problem than cross sections, because they present a three-dimensional picture, they were extended to cover an area reaching from the east rim of the basin to the west rim, and from the region south of Amarillo to the Glass Mountains, an area about 280 miles long and 260 miles wide. Approximately 150 well logs, made from description of cuttings, several Glass Mountains sections measured by Philip B. King and Robert E. King, and one Anadarko basin section after Darsie A. Green were used in the stereograms. Many hundred intervening logs not shown on the stereograms were used for correlative purposes.

The stereograms were originally drawn in color and Oklahoma terminology was used in part for the subdivisions of the Whitehorse group. No further work was done during a year's absence from West Texas. Meanwhile, authors of the West Texas-New Mexico symposium decided to use New Mexico names for the members of this group. Before the writer's return, drafting of the stereograms was well

[3] See footnote 1 for description and prices.

[4] "Stratigraphy of the Permian in Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12 (December, 1937), pp. 1513–73.

under way and the original formation names were being used. For this reason and others which will appear later, Oklahoma nomenclature is retained in this paper.

Since the stereograms were completed a number of deep wells have been drilled in West Texas. As a result, much additional light has been shed on the stratigraphy of the San Andres and older strata. Some of this information as it affects the San Andres is discussed in this paper.

Since this study was begun a number of papers have appeared on the Permian of West Texas and New Mexico. This paper, which was originally written under the title "Upper Permian of West Texas and New Mexico," was rewritten to conform more closely with them. With the appearance of the aforementioned papers the correlation of the San Andres group with rocks in the Delaware basin became the most pressing stratigraphic problem of the South Permian basin. Consequently this paper was rewritten again under the present title.

It has been only within the past few years that many of the geologists of West Texas have begun to differentiate between dolomite and limestone in their sample logs. No differentiation was made between the two in many of the logs used in the stereograms. Consequently their use in the discussion of the stratigraphy of some areas may not be entirely correct in this paper.

ACKNOWLEDGMENTS

Most of the well logs used in this study were loaned to the writer through the courtesy of the many oil companies operating in West Texas. He is especially grateful to Ralph S. Cooley for the presentation of this paper in its first form before the mid-year meeting of the American Association of Petroleum Geologists at El Paso, Texas, in September, 1938. To John W. Skinner the writer is indebted for the information in regard to the fusulines. Appreciation is also expressed to E. Russell Lloyd, Robert E. King, Ronald K. DeFord, John M. Hills, Vaughn C. Maley, John Emery Adams, and John W. Skinner for helpful suggestions and criticism of the manuscript. For the suggested correlations the writer is solely responsible.

MAJOR STRUCTURAL FEATURES

The exceptionally rapid lateral gradation found in the Permian formations of West Texas and New Mexico is usually related, directly or indirectly, to structural relief. It therefore is considered necessary to describe briefly the major structural features before proceeding with the discussion of the stratigraphy. Many have been recognized and described before; others which have not been generally recognized are

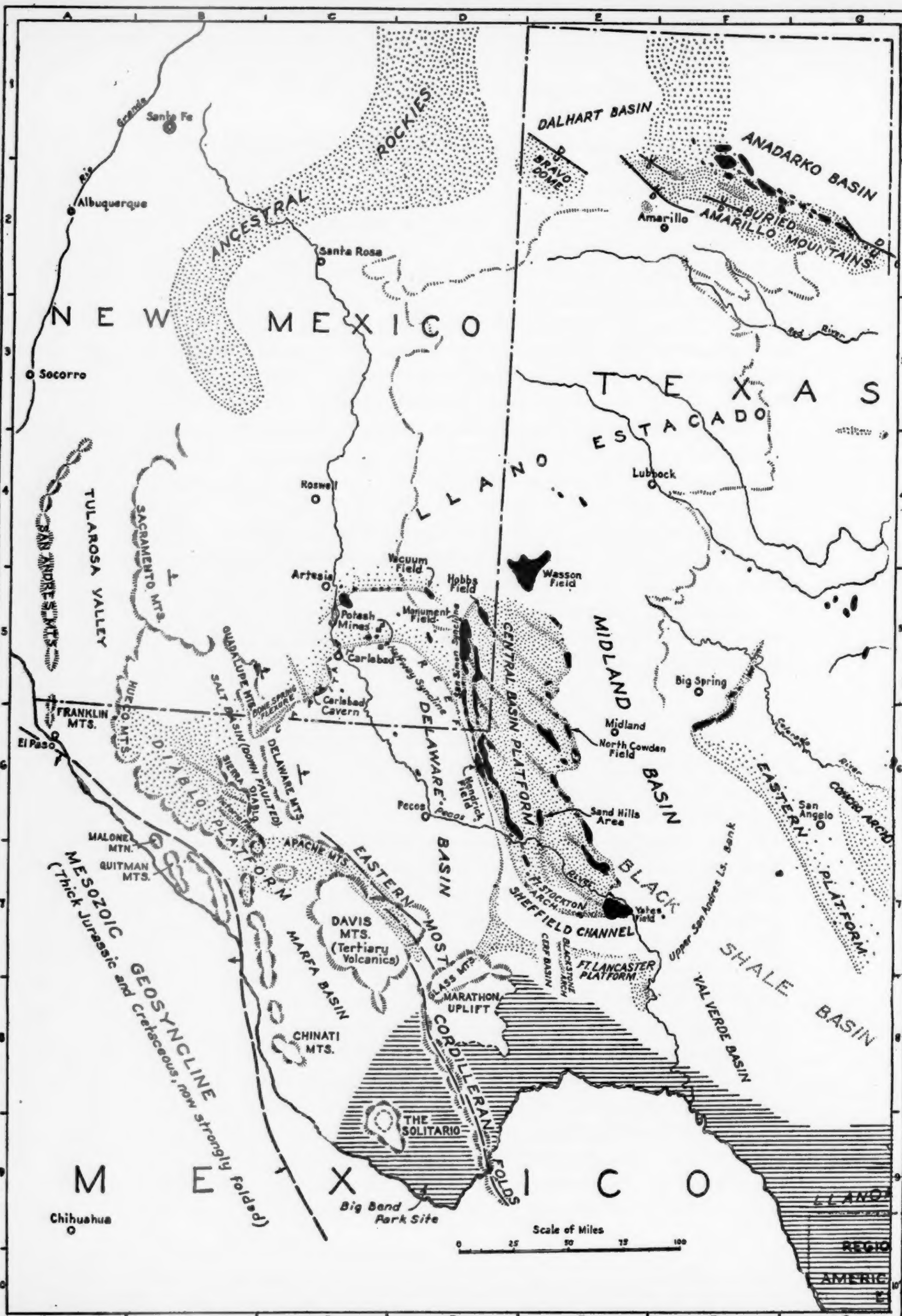

FIG. 1.—Regional structure of West Texas and eastern New Mexico.

referred to, briefly described, and, in a few cases, are here named for the first time.

Figure 1 is a map showing the location of these structural features.

The Central Basin platform is a structurally high area, approximately 40 miles wide and 150 miles long, extending from northern Pecos County into Gaines County. It is comparatively flat-topped, but with steeply dipping limbs defining its eastern and western margins. The backbone of this regional uplift is formed by the Sand Hills arch of Crane County, which was probably an area of some structural relief in early Paleozoic time.

On either side of the Central Basin platform are basins. The Delaware basin on the west is about 100 miles wide and 150 miles long. In southern Lea County, New Mexico, this feature divides to form two synclines. For the one which trends northwest into the vicinity of Halfway, the name Halfway syncline is proposed. For the eastern syncline which extends into the vicinity of Lovington, the name San Simon syncline is given. The Capitan reef bridged the San Simon syncline during late Delaware time, thus forming the north rim of the basin. The Glass Mountains, Davis Mountains, and Apache Mountains delimit the Delaware basin on the south. On the southwest it is bounded by sharp monoclinal flexures in the Sierra Diablo. On its western rim are situated the Delaware Mountains. Delimiting it on the northwest is the Bone Spring flexure.

East of the Central Basin platform is the Midland basin which extends from west-central Crockett County about 175 miles northwest into Terry County. Toward the north the Central Basin platform loses its identity and the deep trough of the Midland basin becomes a broad shallow depression, extending an undefined distance northeast.

The Eastern platform extends from northern Glasscock County, southeast nearly 100 miles into Sutton County. Extending across Glasscock and Howard counties into Mitchell County is the Howard County anticline.

Beginning in the vicinity of Sheffield in southeastern Pecos County the Sheffield channel may be traced westward about 80 miles to a point where it appears to connect with the Delaware basin northwest of Fort Stockton. This feature is bounded on the north by the Fort Stockton arch which forms the south end of the Central Basin platform. Its south margin is a structurally high area reaching from the vicinity of Fort Lancaster in western Crockett County, west across northern Terrell County into Pecos County. The name Fort Lancaster platform is proposed for this feature.

The name Blackstone arch is proposed for that part of the Sand Hills arch situated south of the Fort Stockton arch. It crosses the Sheffield channel and extends toward the southeast corner of Pecos County. The structurally low area which parallels the Blackstone arch and separates it from the Sierra Madera uplift is designated as the Cerf basin. The Cerf basin appears to connect with the Sheffield channel about 15 miles east of Fort Stockton.

Built out toward the north from the Glass Mountains, on the east rim of the Delaware basin, is a limestone reef of Capitan age which may be traced into the area about 8 miles west of Fort Stockton. It appears that this reef may extend from this area north across the Sheffield channel.

Situated in western Edwards and Val Verde counties is a basin which appears to be only a remnant of a larger one that extended into Mexico during Permian time. It is now bounded on the south, apparently, by the metamorphic belt that extends across southern Val Verde County, and roughly by the Pecos River on the west. To this basin of Permian age the name Val Verde basin is given. During Wolfcamp and Leonard time it extended north and occupied the area which in San Andres time became the Midland basin. In it are found several thousand feet of Permian sandstone, which for many years have been regarded as Pennsylvanian (Strawn) in age. These sandstones were believed to be a counterpart of the Ouachita facies lying in the geosyncline in front of Llanoris, like those in the Ouachita, Strawn, and Marathon basins. But from a study of Strawn deposition, it becomes apparent those beds become steadily thinner toward the Permian basin, west of the Llano Mountains and the Concho divide, and are represented by a calcareous facies beneath the sandstones of the Val Verde basin. In the basin just north of Val Verde County, Moore's Perner well No. 1 penetrated several thousand feet of dark shale and sandy shale below the San Andres. In northern Val Verde County the corresponding section is composed chiefly of sandstone, and from it a Permian fauna is reported by Skinner.[6]

In the area west of the Pecos River, the structural attitude of the rocks underlying the Cretaceous is very complex. In east-central Terrell County, Milham, Bassett's well No. 1 encountered about 2,300 feet of dark calcareous shale overlying several hundred feet of dark sandy shale. In the upper series, just below the Cretaceous, graptolites and ostracods resembling the fauna of the Woods Hollow formation of the Ordovician, were found throughout several hundred feet of section by Roth.[5] The lower series does not resemble the strata below the Woods Hollow of the Marathon basin, and may be Permian in age.

[6] John W. Skinner, personal communication (1940).

The exceptional thickness of the upper series, if it is Woods Hollow in age, suggests that the strata are highly tilted. It therefore appears probable that the present western limit of the Val Verde basin, in that area, is bounded by a sheet of overthrust rocks. The belt of metamorphic rocks in southern Val Verde County may be part of an overthrust sheet. The attitude of the Permain rocks in front of this sheet is not known, nor is it known whether the south end of the basin is buried beneath overthrust older strata, or whether it extended southward across the metamorphic rocks during Permian time.

STRATIGRAPHIC FEATURES

The stratigraphic phenomena of the South Permian basin can be largely explained by lateral gradation between sedimentary facies. These changes are of several types: (1) regional gradation of evaporites from salt through anhydrite to dolomite southwestward; (2) regional gradation of marginal coarse clastics through shale to dolomite basinward; and (3) reef deposition with its fore-reef, reef, and lagoonal facies.

Type 1 has been modified in numerous areas by local gradation over structural "highs." Type 2 is found along the east rim of the Midland basin and over the north end of the Fort Lancaster platform. Through lateral gradation clastics pass basinward into limestone and dolomite. In passing still farther basinward, in the Midland basin and in the Sheffield channel, these calcareous beds thin, and thick sandstone beds of a south and west source, appear. This type of gradation resulted in the deposition of the limestone banks which are found on the east limb of the Midland basin and the north margin of the Fort Lancaster platform. Significant examples of type 3 are the reefs exposed in the Glass Mountains and the Guadalupe Mountains.

Reef growth, as shown by subsurface evidence as well as surface exposures, began on the slopes of the higher structural features, and extended basinward in shingle-like pattern, the younger reefs forming on the slopes of the older ones.

Siliceous sediments of probable volcanic origin are present in the Leonard and Word formations of the Glass Mountains. Seemingly these beds pass northward into red, gray and green bentonitic shales. In the region south and east of Fort Stockton and over the south end of the Central Basin platform these bentonitic beds are present at several well marked stratigraphic horizons. Bentonite is found in the lower Whitehorse and in the limestone facies of the Capitan reef in Winkler and Lea counties. In the back-reef area, as dolomite grades laterally into anhydrite, bentonite is found on the fringes of dolomite deposition.

Throughout Permain time dark sediments of southern origin formed in the southern part of the basin, while red clastics derived from the northwest, northeast, and east were deposited on the north.

Because of the numerous changing facies of the South Permian basin, unconformities are recognized by the writer as the best time markers.

STRATIGRAPHY

GENERAL REMARKS

Less is known about the structure and stratigraphy of the Paleozoic rocks buried beneath the Cretaceous in the area between the Sheffield channel and the Southern Pacific Railroad, than any other part of the Permian basin. This region embraces Val Verde, Terrell, and southeastern Pecos counties, and includes the southern extent of the Val Verde basin, Fort Lancaster platform, Blackstone arch, and the Cerf basin. In this area evaporites are not present; structural relief is great and limestone beds grade within a short distance southward into dark shales and sandstone beds of monotonous similarity. The few wells that have been drilled are many miles apart and the lithologic character of the strata encountered does not correspond in any two wells. The writer has attempted to classify the rocks in a few of these wells, with the hope that additional information may come to light through paleontology.

In 1939 a paper was presented by Adams *et al.*[6] proposing that certain rocks in and near the Delaware basin be adopted as a standard section for the Permian of North America, as here shown.

Series	
Ochoa	All Permian rocks above Delaware Mountain group
Guadalupe	Upper Delaware and Capitan
	Lower and middle Delaware, and Word
Leonard	Leonard formation (restricted)
Wolfcamp	Wolfcamp formation (restricted)

This classification was offered by its authors after a study of the paleontologic and stratigraphic evidence of the Delaware basin and the provinces beyond.

The writer is in agreement with this proposed standard section. However, as the classification is extended away from the type area, to the east rim of the basin and northward into Oklahoma, it appears from the writer's study that an error has been made by those authors who propose including the San Andres, and its time equivalent El Reno group, in the Leonard series. Many geologists, including the

[6] John Emery Adams *et al.*, "Standard Permian Section of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1673–78.

writer, believe the San Andres is Guadalupe in age and the boundary line between the Guadalupe and Leonard series should be drawn at the base of the San Andres-El Reno instead of at their top.

The stereogram correlations were arrived at without regard to paleontological studies, but since the San Andres problem has become acute, the writer has made use of what paleontologic evidence is available to supplement the correlations. It has been known for many years that formations or members of formations could be correlated over wide areas, either on the platforms or in the basins, and that problems in correlation develop upon passing from a structurally high area into a low area. It was necessary because of the scope of this study to extend the sections of the stereograms across some of the major structural features in several localities. Also a section was extended from the Delaware basin into the Midland basin by way of the synclinal Sheffield channel.

From this study the two lower divisions of the Delaware Mountain group seemed to be equivalent to the San Andres group. The San Andres was traced into the El Reno. South of Fort Stockton the San Andres seemed to merge with the Word, and it appeared that the Vidrio limestone of the Glass Mountains is upper Word in age. The Whitehorse group appeared to merge with the Gilliam formation. If these correlations are correct, exposures in the Glass Mountains should therefore reveal that: (1) the Vidrio limestone grades into Word clastics toward the west; (2) a basal Whitehorse unconformity separates the Gilliam from the Word; and (3) the unconformity at the base of the El Reno is present at the base of the Word. With these points in mind the writer accompanied two different field parties into the Glass Mountains. From surface exposures the following relations, which will be discussed more fully later, were found. Examination of the base of the Gilliam at the first exposure visited revealed evidence of an unconformity, but its magnitude and extent were not learned. Several hundred feet of clastic rocks of the Word formation were traced into the Vidrio reef. A prominent quartz and chert conglomerate was found resting on the Hess limestone facies of the Leonard, about 300 feet below the base of King's Word.

As a result of this field work it became apparent that confusion existed as to what strata should be included in the Vidrio. King and King[7] used the name Capitan formation to embrace Udden's Vidrio,

[7] Philip B. King, "The Geology of the Glass Mountains, Texas," Pt. 1, *Univ. Texas Bull. 3038* (1930).
Robert E. King, "The Geology of the Glass Mountains, Texas," Pt. 2, *Univ. Texas Bull. 3042* (1930).

Gilliam, and Tessey formations, when they learned that those formations, as described, had only local significance because they were phases of interfingering of changing facies. The formations were consequently reduced to the rank of members and the Capitan was used as a time unit, regardless of facies. Later the Capitan of the type area in the Guadalupe Mountains was defined as a lithologic unit, embracing only the reef facies. Thus the definition in the Glass Mountains did not harmonize with the type section. In their original work, King and King noted the "liming up" of the Word near the reef in the northeastern Glass Mountains and the formation was discussed under the captions "Western Facies" and "Eastern Facies." Several hundred feet of reef limestone which was mapped as Vidrio, they now recognize as upper Word.[8] In order to dispose of a problem of several years standing, regarding the names Vidrio and Capitan, the writer proposed to Philip B. King and the committee on names in West Texas, to restrict the Vidrio to the reef facies of the Word formation. This suggestion has been approved and in this study the Vidrio is regarded as the reef facies of the Word, and the Capitan conforming to its usage in the Guadalupe Mountains, is restricted to the reef facies of the Gilliam formation.

SAN ANDRES GROUP

The name San Andres was proposed by Lee[9] for 500 feet of limestone which is exposed on the west slope of the San Andres Mountains. There it overlies the Yeso redbeds, but its top is concealed under alluvium. Across the Tularosa basin on the east, resting on the Yeso, is a limestone which caps the Sacramento Mountains and extends southeastward into the Guadalupe Mountains. This limestone, which reaches a thickness of 1,250 feet in the northern Guadalupe Mountains, is accepted generally as the San Andres. The Guadalupe and Leonard series were described in part from rocks exposed in the south end of the same mountains. Lang states[10] "The intervening area is most complex; lithologic changes take place within short distances; the limestones become similar in character and are intercalated by numerous sandstones which are repetitional in kind and color. The situation is further complicated by considerable faulting."

Briefly stated the San Andres problem is: does the San Andres pass

[8] Philip B. King, personal communication (1940).

[9] Willis T. Lee, "The Manzano Group of the Rio Grande Valley, New Mexico," *U. S. Geol. Survey Bull. 389* (1909), pp. 12, 14, and 29.

[10] Walter B. Lang, "The Permian Formations of the Pecos Valley of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 7 (July, 1937), p. 855.

beneath the Delaware Mountain group and merge with the Bone Spring limestone to become a part of the Leonard series, or does it grade laterally into the lower two divisions of the Delaware Mountain sandstone to become part of the Guadalupe series?

The San Andres limestone forms the cover rock of the Sacramento cuesta and dips under the Pecos River valley west of Roswell. East of Roswell the limestone unit which lies between the Whitehorse group and the Yeso is generally known as the San Andres. There is general agreement among the geologists of the South Permian basin that the San Andres is equivalent to the El Reno group. In order to avoid the complex area described by Lang, which occurs on the west face of the Guadalupe Mountains near the Texas-New Mexico state line, the writer has attempted to extend the correlations of the San Andres and El Reno groups through the subsurface from the east rim of the basin southwestward into the Glass Mountains and the Delaware basin.

In southeastern Chaves County, New Mexico, the San Andres in the Transcontinental's Robbins well No. 1, is 1,460 feet thick. It is composed of dolomite, or limestone, with a thin member of anhydrite at its top, a thin bed of sandstone near the middle, and a basal sandstone, the Glorieta. It is situated between the redbeds of the Yeso and the Whitehorse group. From that area it may be traced eastward through numerous wells, around the north end of the Midland basin into Crosby County, Texas, thence southeastward into the El Reno group in western Fisher County.

The San Andres group is believed by the writer to represent the lower two-thirds of the Guadalupe series, and is equivalent to the following strata: the El Reno group of Oklahoma, the lower and middle divisions of the Delaware Mountain group of the Delaware basin, and the Word formation of the Glass Mountains.

The beginning of Guadalupe time is significant because of the first widespread distribution of sand in the Permian of the South basin. The El Reno is predominantly sandstone in the southeastern part of the Anadarko basin, and in Kansas the Cedar Hills sandstone is the base of the group.[11] Thick sandstone bodies which the writer believes to be of this age are found in the Delaware basin, Cerf basin, Sheffield channel, Midland basin, Val Verde basin, and the Glass Mountains. The basal member of the San Andres group over a wide area in eastern New Mexico is the Glorieta sandstone and the San Angelo sandstone and conglomerate is found at the base of the El Reno along its entire length of outcrop in Texas.

[11] George H. Norton, "Permian Redbeds of Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939).

EAST RIM OF BASIN

In 1928, Buckstaff, Schweer, and Moore applied the term "El Reno group" to the formations occupying the interval between the base of the Duncan sandstone and the base of the Marlow formation of the Whitehorse. Since it is almost unanimously accepted now, by geologists in Oklahoma and Kansas, that the Duncan and Chickasha sandstones are the deltaic facies of the Flower-Pot, Blaine, and Dog Creek formations, the term is applied to both basin and deltaic facies. The San Andres is generally recognized as the limestone facies of the same group.

The El Reno group extends across Red River and can be traced southward across Texas 250 miles before it is lost under Cretaceous rocks. In Oklahoma the middle formation of the group is the Blaine gypsum, but in Texas thick beds of gypsum develop above and below the Blaine. The writer has made no attempt to divide the group into formations in this study.

In an article in 1891 Lerch[12] proposed the name "San Angelo beds" for 12 feet of conglomerate and 100 feet of overlying sandstone and intercalated red and yellow shale, cropping out at Ben Ficklin crossing, just south of San Angelo. Beede and Bentley[13] proposed the name San Angelo formation for a section of beds in Coke County, which included not only the original San Angelo beds, but also 220 feet of overlying red and green shale and an upper capping conglomerate. The shale is probably Flower-Pot in age, and the upper conglomerate is now known to be the basal conglomerate of the Whitehorse group. The coarse material of this conglomerate and of the San Angelo conglomerate was probably derived from a land area to the southeast.

An unconformity separates the El Reno group from the Clear Fork (Leonard) and the San Angelo rests on the eroded beds of the Clear Fork as shown by Wrather[14] and Mohr.[15] Evidence of this hiatus is also found in many wells drilled near the west edge of the Eastern platform. The strata of the Clear Fork group grade southwestward from red clastics to limestone on the Eastern platform. From the west edge of the platform these limestone beds dip sharply toward the Midland

[12] Otto Lerch, "Remarks on Geology of the Concho Country, State of Texas, *Amer. Geol.*, Vol. VII.

[13] J. W. Beede and W. P. Bentley, "The Geology of Coke County," *Univ. Texas Bull. 1850* (1918).

[14] W. E. Wrather, "Notes on the Texas Permian," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917).

[15] C. L. Mohr, "Subsurface Cross Section of Permian from Texas to Nebraska," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), p. 1705.

basin and grade abruptly into dark shales, the gradational strike being southeast. The facies of the El Reno on the other hand was not affected by the Eastern platform. The gradational strike of the strata of this group in Tom Green County is northeast, and the red and green shales which are present on the platform extend westward across this feature and dip into the Midland basin in the western part of the county. Thus the gradational strikes of the two groups, separated by the San Angelo conglomerate, are disconformable by many degrees. On this basinward dip, that part of the El Reno group above the San Angelo thickens within a short distance and grades into a limestone bank in the eastern part of the Midland basin. The San Angelo interval also thickens and is filled with sandstone which the writer believes to be of a western source. These two divisions form the San Andres group. This is the only area, so far as the writer is aware, where the San Angelo can be traced into the Midland basin. It is important because it furnishes a correlation by which the San Angelo time equivalent can be identified in the structurally low area on the west and southwest.

In its southern exposures the San Angelo is but a short distance from the west edge of the Eastern platform but to the northeast it recedes farther and farther from that feature. The outcrop of the San Angelo is 50 miles east of Howard County, and in this segment of the basin situated between the outcrop of the San Angelo and the east lines of Borden, Howard, and Glasscock counties, the El Reno thickens westward and grades from red shale and gypsum through green shale and anhydrite into dolomite. Across this distance the coarse sediments of the San Angelo become finer and the formation seems to thin and disappear. Thus in the eastern part of these counties is a limestone bank, comprised of that part of the El Reno above the San Angelo, about 750 feet thick, which rests directly on the Clear Fork limestone. This sequence appears to persist through the Howard County anticline and southward into Glasscock County. Here again because the gradational strike of the Clear Fork beds on the west rim of the Eastern platform is southeast, the limestone bank of the upper San Andres crosses the platform edge at an angle and extends downward into the Midland basin. Between the upper San Andres and the Clear Fork, on this sharp dip, a wedge of sandstone, the lower division of the San Andres which is the time equivalent of the San Angelo, appears and thickens basinward. It therefore appears that, in parts of Borden, Howard, and Glasscock counties where the upper division of the San Andres rests on the Clear Fork, the lower division disappears by overlap against the west limb of the Eastern platform.

MIDLAND BASIN

The red clastics of the El Reno disappear in the Midland basin as they merge with the San Andres group. Over most of the basin the San Andres is separable into an upper dolomitic member and a lower sandy member, the sands of which according to the writer's interpretation entered the basin through the Sheffield channel. The relation of the El Reno to the San Andres is clearly shown by many wells situated on the east rim of the basin.

In the Stanolind's Williams well No. 1, southeastern Irion County, the upper division, which still retains a large amount of red and green shale, was encountered immediately below the Trinity sandstone, at 640 feet. The lower sandy division, which here contains limestone beds, was found from 1,125 to 1,825 feet.

Structurally lower in the Midland basin, the red and green shales merge with dolomite, in the previously mentioned limestone bank, which in western Irion County ranges from 700 to 800 feet thick. The lower division is composed principally of sandstone. Instead of thickening still further basinward the upper division thins and sandstone beds appear in the dolomite. In the Big Lake oil field the upper division is about 600 feet thick and much of the section contains thin sandstone beds. The lower division is 1,000 feet thick and consists of sandstone and intercalated thin black shale beds. Near the axis of the Midland basin, in Upton County, the Humble's Pollock well No. 1, encountered about the same thickness of San Andres as found at Big Lake, but the upper division contains about 300 feet of sandstone, and the shale beds are thicker in the lower division. On rising to the rim of the Central Basin platform, in west-central Upton County, the San Andres thins from about 1,600 feet to 1,450 feet and both divisions appear to grade into dolomite.

Northwest from Big Lake the upper calcareous division is sandy as far as Andrews County. The lower division grades from sandstone and black shale to black shale and limestone and in northern Ector County it reaches up onto the edge of the Central Basin platform. That these limestone and black shale beds are in the lower San Andres is also suggested by the section penetrated in the Humble's Westheimer well No. 1, about 100 miles northwest, in northern Cochran County. North of this area the San Andres consists principally of anhydrite and salt, but in the Humble drill hole, where the group is 1,300 feet thick, in its lower part, resting on the Yeso, is about 250 feet of limestone and thin black shale partings. The upper part of the group consists of about equal parts of anhydrite and dolomite, so that the

mere presence of a limestone facies so far north indicates that there is probably a thicker body on the south.

North from Big Lake in the Midland basin, sandstone beds are present in the upper division of the San Andres as far as Borden County. In the structurally low area north of the Howard County anticline, west of Big Spring, a recently drilled well, Shaw's Wilkerson No. 1, reveals this division about 600 feet thick. Here it contains several sandstone beds. The lower division is composed of sandstone with intercalated limestone and black shale beds. The presence of sandstone in the upper division of the San Andres so far north in the Midland basin has led some geologists to believe that these beds are Whitehorse in age, older than Marlow (Grayburg), or that they belong to strata lying between the Whitehorse and the San Andres. East of this area, the lower division seemingly disappears by overlap and the upper one, losing its sand, thickens and passes into the limestone bank of eastern Howard County, where it rests on the Clear Fork.

South from Big Lake in the Midland basin, the thin black shale beds of the lower division of the San Andres are replaced by sandstone, and there is a marked increase of sand in the upper calcareous division, as the entrance of the Sheffield channel is approached. Just east of the Yates field, near the axis of the Midland basin, the upper division is composed of alternating dolomite and sandstone beds of about equal thickness. To the east in north-central Crockett County it merges with the limestone bank where it is 800 feet thick. The lower sandstone division, in this higher structural area, passes into dark sandy shale and gray-green bentonite about 600 feet thick. It will be noted on the stereogram that the base of the San Andres was drawn at the base of the upper dolomitic division in the Stanolind's Todd well No. 1. *This is an error.* The base of the group should be lowered about 600 feet. A log made several years ago was used in this study and this interval was shown as shale. Recently it was discovered from a newly made log that it consists of sandy shale. It is evident that this division is grading eastward into shale and in eastern Crockett County, the lower division of the San Andres should be dark shale, resting on dark shales of the Clear Fork.

The limestone bank which may be traced from southeastern Borden County southward along the east rim of the Midland basin, swings southwest in central Crockett County, crosses the Pecos River and continues westward on the north rim of the Fort Lancaster platform. Thus this feature closed the Val Verde basin and formed the south limb of the Midland basin. The relation of the San Andres group to the limestone bank in this area, is revealed by a number of drill

holes extending from near the Yates field southward down the Pecos River.

Just east of Yates, in the Gulf's Thompson well No. 1 in western Crockett County, drilling was abandoned after penetrating 300 feet of dolomite with intercalated sandstone beds, overlying 800 feet of siliceous sand with a few thin cherty limestone beds. Proceeding southward from this well, updip, sandstone grades rapidly into cherty dolomite. The gradation of sand to dolomite begins at the top of the section and becomes progressively lower and lower in the section to the south, until just east of the northeast corner of Terrell County, in Moore's Perner well No. 1, the San Andres consists of about 200 feet of green bentonitic shale, resting on 600 feet of light-colored dolomite which overlies dark cherty dolomite, or limestone, 400 feet in thickness. Below that member is about 100 feet of gray bentonitic shale, which the writer provisionally places at the base of the San Andres. The entire absence of sand in the San Andres which formed the limestone bank, indicates that the sediments which entered the Midland basin at Sheffield moved northward down the basin. In this area, seemingly both divisions of the San Andres are calcareous.

Farther southward the limestone of the bank grades into clastics in the Val Verde basin. In northern Val Verde County the San Andres time equivalent appears to consist of black shale with numerous thin sandstone beds, the material of which encroached from the south. In southeastern Crockett County the Trinity overlap has removed the upper part of the San Andres and only 1,100 feet of beds are present in the Marland's Pierce well No. 1. There the group consists of limestone, or dolomite, red, green, and black shale and a basal sandstone about 250 feet thick.

SHEFFIELD CHANNEL

The Sheffield channel was named in 1932 by Cannon and Cannon[16] when its character and importance were recognized. During San Andres time it was an avenue through which siliceous sands and bentonite from the Cerf basin and sands from the Delaware basin moved into the Midland basin. The Channel was the most striking and one of the most important features in the South Permian basin during that period. It was a structurally low area, filled principally with sandstone, cradled between the Central Basin platform and the Fort Lancaster platform. The sandstone beds of the channel reach updip toward the

[16] Robert L. Cannon and Joe Cannon, "Structural and Stratigraphic Developments of South Permian Basin, West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 2 (February, 1932), p. 199.

north and south, and grade into light-colored dolomite of San Andres age.

West of Sheffield a number of drill holes encountered alternating dolomite and sandstone beds several hundred feet thick without reaching the base of the group. On the north rim of the channel, a few miles west of the Yates field, the Gulf's White and Baker well No. 1 encountered about 1,400 feet of San Andres, which consists of light gray and buff-colored limestone, or dolomite, with a few thin beds of intercalated sandstone, resting on dark limestone. On the south, on the Fort Lancaster platform, the time equivalent beds are light-colored limestones overlying dark limestones of the Leonard. Over the north end of the Blackstone arch, the channel is bridged with 600 feet of dolomite which rests on sandstone of Delaware and Word origin, about 1,300 feet in thickness, as revealed in the Phillips' Heyman well No. 1. On the Fort Stockton arch, just north of the channel, the Shell's University No. 1 encountered 1,400 feet of San Andres. There it is composed of gray, buff, and white dolomite. The base of the group, which rests on dark calcareous beds, is at sea-level. In the channel just north of Fort Stockton, the Pinal Dome's Devlin well No. 1, the San Andres time equivalent consists of about 200 feet of dolomite, overlying several hundred feet of alternating dolomite and sandstone beds. The channel appears to connect with the Delaware basin about 10 miles northwest of Fort Stockton. Seemingly the siliceous sediments which are found in the east end of the channel entered it through the Cerf basin, because in the area west of the junction of the structurally low features, the sands have a Delaware aspect.

AREA SOUTH OF SHEFFIELD CHANNEL

From the limestone bank situated on the north margin of the Fort Lancaster platform, the San Andres limestone grades normally southward into black shales, maroon, green, and brown siliceous shales and siliceous sand. West of the Cerf basin, between Fort Stockton and the Glass Mountains, the Southern Crude's Scharbauer well No. 1 penetrated 1,600 feet of light-colored dolomite overlying dark cherty limestones and black shale beds of the Leonard. There thin sandstone beds occur near the mid-section of the group. West toward the Delaware basin the lower half of the San Andres consists of alternating sandstone and limestone beds. Southward the San Andres appears to merge with the dolomite and limestone facies of the Word formation.

The stratigraphy in the region of the Blackstone arch and the Cerf basin is very complex, but enough information is available to indicate the magnitude of the features. The Cerf basin separates the Black-

stone arch from the Glass Mountains, Sierra Madera uplift, and the platform area between the Glass Mountains and Fort Stockton. The limestone bank of the Fort Lancaster platform extends west across the Blackstone arch. Between the Transcontinental's Blackstone No. 1, which was drilled on the arch, and the Wilcox's Cerf No. 1, situated in the basin 6 miles west, there is more than 2,000 feet of dip. This sharpness and amount of dip on the west limb of the Blackstone arch is comparable with that found on the west face of the Central Basin platform. As in other structural "lows" in the South Permian basin the sediments in the Cerf basin are sandy; however, in this area they are siliceous sands and the shales are siliceous. About 1,900 feet of beds in the basin, which appear to comprise the Whitehorse group and the overlying Ochoa series, are cut out on the arch by the Trinity overlap, and about 700 feet of siliceous sediments disappear by overlap against the west limb of the arch.

Resting on these sediments that lense out is a coarse conglomerate which is overlain by 900 feet of siliceous sands and shales. It is believed by some geologists that this conglomerate is the base of the Leonard series and the sediments below it are Wolfcamp in age. However, since the Wolfcamp series in the Glass Mountains is typically marine and the only beds which contain siliceous sediments are in the Leonard and the Word, it is believed by the writer that the conglomerate is at the base of the Word, and it is the Leonard that lenses out against the Blackstone arch.

GLASS MOUNTAINS

The descriptive geology and the paleontology of the Word formation and the Vidrio are ably discussed by Philip B. King and Robert E. King.[17] The aspect of the Word is characteristically siliceous. The shales are radiolarian-bearing and siliceous; the limestone beds contain many chert nodules and layers, and the fossils are silicified. The outcrop is generally strewn with yellow siliceous shale and sandstone float. In passing into the eastern Glass Mountains the facies undergoes a change. About 5 miles north of the Iron Mountain uplift, in Gilliland Canyon, the formation becomes more calcareous, the yellow float disappears and the limestone ledges coalesce to form thick beds. Along the base of the Vidrio reef several hundred feet of thin-bedded limestone and sandstone beds of the Word may be traced into massive Vidrio reef dolomite. The gradation is rapid and long foreset beds dip at sharper angles than the bottomset beds.

[17] Philip B. King and Robert E. King, *op. cit.*

East of Gilliland Canyon the Vidrio extends as the upper division of the Word. King and King show that the Vidrio is separable from the lower division in that it is more dolomitic and is thicker-bedded, and contains fewer fossils and less chert. That the Word is capable of being divided into two units is important, because the San Andres, which the writer believes is the time equivalent of the Word, consists of two units in a large part of the South Permian basin, and the upper one is composed chiefly of dolomite.

It is interesting at this point to note King's[18] comparison of the Glass Mountain sections with the section penetrated in the Vacuum's Elsinore well No. 1, which is situated about 20 miles north of the mountains.

With the exception of a small variation for the top of the Gilliam, the boundaries of the formations set out in King's correlation are identical with those of the writer, the Vidrio being the top of the San Andres and the base of the Word the base of the San Andres. Instead of proceeding northward from the Glass Mountains, the correlations used in the stereograms were extended southward through the basin to this well.

Where in the Glass Mountains is the unconformity which should represent the hiatus found at the base of San Angelo on the east rim of the basin? This question has been asked many times during the past 10 years. King and King drew the base of the Word at the base of a limestone ledge to which they refer as the First Limestone member, because it is near a faunal change and the bed is present over a wide area in the Glass Mountains. They were also influenced in using this horizon by a desire to conform as closely as possible to Udden's earlier interpretation.[19]

In the eastern Glass Mountains, after the Leonard has attained its eastern limestone facies (Hess), there is a limestone containing an abundance of rounded quartz and chert pebbles, resting on the Hess. King and King measured this conglomerate in a number of sections and recognized it as far northeast as the Sierra Madera. Although it is not as continuously exposed in some areas as the First Limestone bed, it is identifiable over a much wider area and it appears to be a more natural boundary line for the base of the Word. The conglomerate is well displayed in the upper reaches of a narrow canyon about one mile west of the old Word ranch house. The First Limestone mem-

[18] Philip B. King, *op. cit.*, p. 78.

[19] Robert E. King, personal communication (1940), states "We were greatly influenced by Udden's work, and I don't believe it ever occurred to us that the base of Udden's Word was not a natural stratigraphic division."

ber is about 300 feet above the conglomerate. The intervening section is composed of yellow marl, siliceous shales, limestone beds, and some sand layers, which are also characteristic of the formation above the First Limestone bed. Thus with a possible unconformity at the top of the Vidrio member of the Word and one at the base of the Word, like the El Reno group which is also separable into two divisions, the two are bounded by unconformities.

DELAWARE BASIN

In the Delaware basin, the Delaware Mountain group comprises the Guadalupe series. This group has been divided into three units, each of the lower two being about 1,000 feet thick, and the upper one about 700 feet thick. For many years these divisions have been referred to as lower, middle and upper. King[20] has raised each of these divisions to formational rank to which the names Brushy Canyon, Cherry Canyon, and Bell Canyon are given. Hereafter in the discussion of the Delaware basin, unless otherwise indicated, references made to King refer to this paper.

The Brushy Canyon is composed of sandstone and the Cherry Canyon contains siltstone, shale, and several limestone beds. These two formations were continuous throughout the Delaware basin and they extended northward into the San Simon syncline and eastward through the Sheffield channel into the Midland basin. From their outcrops in the Delaware Mountains they thicken from 2,000 feet to 2,545 feet in the subsurface toward the northeast. Southeast toward the Glass Mountains the Delaware Mountain group thins and in southwestern Pecos County, in the Humble's Kokernot well No. 1, it was encountered from about 3,975 to 5,759, 1,775 feet in thickness. There the lower half of the group consists of black shale, limestone, and thin sandstone beds, and thick limestone beds are present in the upper half. When this marine section is compared with its time equivalent, the very siliceous sediments of the Word, it indicates that the Vidrio reef, which was growing on the southeast rim of the basin, acted as a barrier and restricted the movement of the Word sediments and kept a large part of them from entering the basin.

Northward in the exposures of the Delaware Mountains, limestone becomes more prevalent in the upper two divisions of the group. To the most prominent members of the Cherry Canyon, King has given the names, in ascending order: Getaway, South Wells, and Manzanita. The Getaway is near the base of the formation, and the Manzanita at its top. In this area the northwest rim of the Delaware basin is formed

[20] Philip B. King, "West Texas Permian," forthcoming paper.

by the Bone Spring flexure. Against its sharp basinward dip the Brushy Canyon begins to lens out. This overlap continues northward to the vicinity of Bone Spring, just south of Guadalupe Point, where the entire 1,000 feet of sandstone disappears by overlap. Situated above this division, the Cherry Canyon extends across the overlapping beds and comes to rest on the Bone Spring limestone of the Leonard series.

As previously discussed under the chapter "East Rim of Basin," the San Angelo sandstone, which appears to be the time equivalent of the lower division of the San Andres and the Brushy Canyon, does not reach across the north end of the Eastern platform. There the upper San Andres, which appears to be Cherry Canyon in age, rests on the Clear Fork. The lower San Andres seemingly disappears by overlap against the platform.

It is believed by most geologists that the Glorieta sandstone is equivalent to part of the San Angelo. Both formations are shelf area deposits. Because of the many drill holes on the east rim of the basin, the extent and structural attitude of the San Angelo is well known, but less is known of the Glorieta in its southernmost extent. Blanchard and Davis[21] show that it is faulted out at the south and its most southern exposure is seen in the west scarp of the Guadalupes, 10 miles north of Bone Spring. The Glorieta does not reach the exposures of the Bone Spring flexure. Consequently its relation to the Brushy Canyon can not be shown. Strata of Brushy Canyon age lens out against the Bone Spring flexure and probably against the Eastern platform, and beds of Cherry Canyon age reach onto these features where they rest on the Leonard series. It appears to the writer that there is an analogous set of facts which accompanied the deposition of contemporaneous beds on the two major features which formed the east and west margins of the deeper part of the South Permian basin.

Because the Brushy Canyon formation is seen to overlap against the Bone Spring flexure, it is believed by some geologists that this division is confined to the Delaware basin as a lentil. As seen from a study of the strata in the basin during the period succeeding Guadalupe time, the east rim of the basin was a comparatively small structural feature. The sagging of the Midland basin, Sheffield channel, and Delaware basin, which began with Guadalupe time, ended in the Midland basin and the Sheffield channel with the close of that period. The Delaware basin continued to sink rapidly and in it was deposited

[21] W. G. Blanchard and M. J. Davis, "Permian Stratigraphy and Structure of Parts of Southeastern New Mexico and Southwest Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 968.

the Castile (lower Castile), as a lentil. This formation is about 2,000 feet thick in the basin just west of the reef which forms the west limb of the Central Basin platform. It seems, therefore, that the structural relief of the Delaware basin was 2,000 feet less at the close of Guadalupe time than it was later at the close of Castile deposition. The sandy sediments of the Brushy Canyon are confined, in a general way, to the structurally low areas of the South Permian basin, but appear to be represented by a calcareous facies over the platform areas.

King, in a concise manner, shows the relation of the Cherry Canyon formation of the Bone Spring area to the reef dolomites underlying the Capitan reef in the west face of the Guadalupe Mountains. There, as previously stated, the Cherry Canyon rests on the Bone Spring limestone. Just north of Bone Spring, the Getaway and South Wells limestone members, separated by 600 feet of sandstone, thicken. Still a little farther north these limestone members coalesce and merge with a tongue of reef limestone 700 feet thick, described by Lang.[22] The Manzanita limestone member, which contains several bentonitic shale beds, and immediately above which is found the lowest species of the fusuline *Polydiexodina*, forms the uppermost beds of the Cherry Canyon. The reef beds, as shown by King, merge with that portion of the Cherry Canyon below the Manzanita, and it appears that this member pinches out against the thickening reef. Still a little farther north the reef increases in thickness to about 1,200 feet, which is about the thickness of the San Andres in the northern Guadalupes.

Lang states that this calcareous facies of the Cherry Canyon is below the Rush Springs (Queen) formation of the Whitehorse group. In the back reef area of New Mexico the interval that lies between the Rush Springs and the San Andres, is the Marlow (Grayburg) formation, which is 300 feet in thickness. Some geologists believe that the Marlow formation is equivalent to the Cherry Canyon, but to the writer, because of their unequal thickness, this correlation seems very improbable, especially since both formations are shelf deposits. It appears that the Cherry Canyon reef is the time equivalent of the Vidrio reef of the Glass Mountains and the writer concurs with Dickey[23] in his belief that the Cherry Canyon and San Andres are for the most part contemporaneous deposits.

That the Cherry Canyon reef is confined to the shelf area is evidenced by several wells drilled on the Capitan reef. The Bell Canyon formation of the Delaware Mountain group, grades into the Capitan

[22] Walter B. Lang, *op. cit.*, p. 858.

[23] Robert I. Dickey, "Geologic Section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 43.

limestone facies. The top of the Manzanita member is the "upper dark limestone" at Guadalupe Point, on which the Capitan rests, and the green siliceous bentonitic shale bed 300 feet below the dark limestone, is a prominent bed within the Manzanita. On the reef about 50 miles northeast of the Point, the Ohio's Tracy well No. 1 penetrated 2,600 feet of Capitan limestone. At that point the Manzanita was encountered and the siliceous bentonite was found near 2,920 feet. The thickness of the Cherry Canyon and the Brushy Canyon is about 2,300 feet, and the Cherry Canyon is composed of sandstone and intercalated black shale beds.

In late Guadalupe time the Capitan reef formed the northern curve of the Delaware basin. On the reef, about 15 miles northeast of Carlsbad, the Getty's Dooley well No. 7 encountered the base of the Capitan and the top of the Cherry Canyon formation at 3,720 feet. Here again, as at Guadalupe Point, the top member of the Cherry Canyon is the Manzanita member. The green siliceous bentonitic shale was encountered from 4,040 to 4,050 feet. The Cherry Canyon is composed principally of sandstone and black shale beds. In this well the lower two divisions of the Delaware are 2,545 feet thick. The top of the Bone Spring was found at 6,265 feet.

This evidence indicates that the Cherry Canyon and Brushy Canyon formations extended northward in the Delaware basin, beneath the Capitan reef, as a sandstone facies. In the back reef area of west-central Lea County, a few miles east of the type locality of the Grayburg,[24] in an area where the base of the Whitehorse group is easily distinguished, the Henderson's Wyatt well No. 1 penetrated nearly 800 feet of section below the Marlow. The base of the Marlow was found at 4,600 feet and the formation consists of 300 feet of dolomite, anhydrite, and a few thin beds of sandstone and bentonite. The section beneath the Marlow is composed of thick dolomite beds with thin gray sandstone layers in its upper part, which becomes steadily more sandy at the base. The lower 300 feet of beds penetrated consist chiefly of sandstone, which in aspect is typically Delaware. It appears that the sandstone beds of the Cherry Canyon are grading northward in the back reef area into dolomite. Further evidence that the Marlow is younger than Cherry Canyon, and is thus equivalent to the lower Capitan, is seen in many wells in the back reef area of Winkler and Lea counties. Upon approaching the reef, the Marlow, instead of grading into sandstone, becomes steadily more calcareous and in this facies the writer is not able to distinguish it from the other formations of the Whitehorse group in the reef.

[24] Robert I. Dickey, *op. cit.*, p. 45.

The shelf areas of San Andres age, on the east and west rims of the Delaware basin, are immediately behind the Capitan reef, but on the north rim of the basin it appears to be some 20 miles behind. As the northwestern shelf recedes from the reef in Eddy County, the Cherry Canyon and Brushy Canyon appear to grade into the San Andres group. About 30 miles northwest of the Henderson's Wyatt well, the Transcontinental's Robbins No. 1 encountered 1,460 feet of San Andres, from 2,020 to 3,480 feet. Drilling was abandoned after penetrating 1,500 feet of Yeso. A thin remnant of seeming Delaware sand is found near the middle of the San Andres.

In the San Simon syncline, the lower two divisions of the Delaware Mountain group appear to grade northward, as they do in the Midland basin, into an upper dolomite and lower limestone division. In the Western Minerals' Dow No. 1, Sec. 27, T. 10 S., R. 30 E. (well not on stereogram), the top of the San Andres was found at 2,870 feet and drilling was abandoned in that group below 4,060 feet. From 2,870 to 3,546 feet the section consists of dolomite and anhydrite, and from 3,546 to 3,990 feet, limestone with traces of black shale. North and northeast of this area the San Andres grades into evaporites but limestone is present in the lower division in Cochran County, as already mentioned.

CENTRAL BASIN PLATFORM

Some of the deeper wells drilled on the Central Basin platform after completion of the stereograms are used in the discussion of the San Andres group. North of the platform in Cochran and Yoakum counties, the upper part of the San Andres consists largely of anhydrite with thin dolomite beds. In Cochran County, as previously mentioned, the San Andres is about 1,300 feet thick. In southwestern Gaines County in the Humble's Eubank No. 1, about 1,600 feet below the top of the group, a thin bed of red shale was found. This bed is probably within the Yeso. The San Andres is composed chiefly of dolomite and the two divisions which may be recognized on the west, north, and southeast, can not be identified. The well was drilled with rotary tools and the top of the group is difficult to determine, but it is believed to be near 4,350 feet.

Farther southeastward in Ector County, on the east rim of the platform, the two divisions of the San Andres are again found. In the North Cowden pool the upper division consists of about 500 feet of dolomite with intercalated sandstone beds, and the lower is composed of limestone and thick black shale beds. The newly discovered "Holt pay" is, the writer believes, in a limestone of upper Leonard age. In this area several wells have been drilled to the "Holt pay" and by

correlation from well to well, using the limestone beds and shale partings, the limestone beds are seen to grade laterally into dolomite toward the platform. A few miles back from the platform edge both divisions of the San Andres group are composed of dolomite and the group is a unit.

The deep well drilled by the Gulf, the McElroy No. 103, situated near the steeply dipping limb of the Central Basin platform in west-central Upton County, encountered 1,450 feet of light-colored dolomite resting on a thin basal sandstone. These strata are believed to be the San Andres. The underlying beds are darker-colored limestones, or dolomite, believed to be the Leonard.

Over the south end of the Central Basin platform, in northern Pecos County, the San Andres is composed of about 1,400 feet of light-colored dolomites, and in a few wells, intercalated thin sandstone beds are found. There too the underlying Leonard series is composed of dark calcareous beds.

PALEONTOLOGY

In 1937 Dunbar and Skinner[25] divided the Permian rocks of the trans-Pecos region into major fusuline zones, as follows.

	Glass Mts.	*Guadalupe-Delaware Mts.*
Zone of *Polydiexodina*	Capitan	Capitan and upper Delaware Mountain
Zone of *Parafusulina*	Word	Middle and lower Delaware Mountain
	Leonard	Bone Spring
Zone of *Pseudoschwagerina*	Wolfcamp	(Not exposed)

In the paper presented by Adams *et al.*[26] the zone of *Parafusulina* was divided, and the Leonard formation was designated as the Leonard series. To the upper division, which was named the Guadalupe series, the upper part of the zone of *Parafusulina* was added. The subdivisions of the Permian made in this paper are in close accord with the study made of the ammonoid-bearing beds of the Guadalupe Mountain region by Miller and Furnish.[27]

Designated in the foregoing studies as characterizing the Leonard series are small forms of fusulines, *Parafusulina*, a few brachiopods, and the ammonoid *Perrinites*. The Guadalupe series is characterized by markedly more advanced forms of *Parafusulina* than those of the Leonard, such as *Parafusulina rothi* and *P. sellardsi*. The ammonoids are represented by *Waagenoceras*. The upper unit of the Guadalupe

[25] Carl O. Dunbar and John W. Skinner, "Permian Fusulinidae of Texas," *Univ. Texas Bull. 3701*, Vol. 3 (1937), p. 581.

[26] John Emery Adams *et al., op. cit.*, p. 1675.

[27] A. K. Miller and W. M. Furnish, "Permian Ammonoids of the Guadalupe Mountain Region and Adjacent Areas," *Geol. Soc. America* (March 15, 1940), p. 9.

series, which is the Gilliam formation and its equivalents, the Capitan limestone and the Altuda member in the Glass Mountains, and the Bell Canyon formation and the Capitan limestone in the Guadalupe Mountains, is characterized by the fusuline *Polydiexodina*. *Waagenoceras* is still present in this division and is associated with a more advanced type of ammonoid, *Timorites*.

In the northeastern Glass Mountains thick limestone ledges develop in the Word formation and it passes into a calcareous facies like the underlying Leonard. The dividing line between the Leonard and Guadalupe series was drawn at the base of a limestone ledge, about 300 feet above a conglomerate which rests on the limestone facies of the Leonard. If the base of the Word formation is lowered to this conglomerate, as proposed by Mohr[28] and the writer, then *Perrinites* is present in the basal beds of the Word, or the Guadalupe series. In the sandy facies of the western Glass Mountains, King[29] reports *Perrinites* in beds above the conglomerate in the Dugout Mountain Section 7, and in the Sullivan Peak Section 12. On the east, where the Word becomes more calcareous, *Waagenoceras* is found in the First Limestone member.

Since the Word, in the eastern Glass Mountains, is known to grade into the dolomitic reef facies of the Vidrio, species of *Parafusulina sellardsi* and *P. rothi* which have been reported from the middle and upper Word, are in strata of the lower division of the formation. The dolomitized limestones of the upper facies contain few fossils and the writer has no information on its fusulines or ammonoids.

In the Delaware basin the genus *Parafusulina* ranges throughout the Brushy Canyon and Cherry Canyon formations of the Delaware Mountain group, and the species *Parafusulina rothi* is found in both formations. No ammonoids are known from the Brushy Canyon, and *Waagenoceras* does not appear below the South Wells member of the Cherry Canyon,[30] which is only 400 feet below the top of the middle division of the Delaware. To the northward as the Cherry Canyon formation grades into reef limestone, ammonoids have not been found, but *Parafusulina* zones extend into the reef. It therefore appears that fusulines which are found over such a wide area, and in various facies, are not as dependent on facies as the ammonoids. The restriction of ammonoids by facies is again seen in the Glass Mountains, where the Hess limestone facies of the Leonard has yielded only a few.

In New Mexico, only a single Permian ammonoid has been found. It was collected by Beede in the San Andres near Cloudcroft and has

[28] C. L. Mohr, *op. cit.*, p. 1705.
[29] Philip B. King, *op. cit.*, pp. 132 and 135.
[30] A. K. Miller and W. M. Furnish, *op. cit.*, p. 10.

been identified by Miller and Furnish as a representative of *Perrinites hilli.*

Two collecting grounds in the El Reno group on the east rim of the basin have yielded ammonoids, one at the falls of Salt Croton Creek, Stonewall County, and the other about 6 miles west of Quanah, Hardeman County. Plummer and Scott[31] believe these forms to be more highly developed than the *Perrinites* of the Leonard and consequently younger than Leonard. They tend to emphasize small changes in form and suture, while Miller and Furnish believe such changes have no value as stratigraphic markers. The latter believe that all the ammonoids of the El Reno are forms of *Perrinites hilli* and consequently are Leonard in age.

It is unfortunate that fusulines are not present in this series of beds which compose the El Reno group. It consists of red shale, gypsum, and thin dolomite beds. In passing north from Howard County the beds which form the El Reno have apparently been altered by diagenesis and fossils are very rare. However, as these strata grade into the more marine beds of the San Andres, basinward, fusulines make their appearance and in some localities are numerous. Through the studies of John W. Skinner on the fusulines found in many wells in the South Permian basin, where ammonoids have not been reported, a preponderance of evidence has shown that the strata of the El Reno and San Andres groups are characterized by *Parafusulina rothi* and *P. sellardsi.*

A recently drilled well, situated on the limestone bank in Crockett County, the Humble's Ozona Barnhart Trapp Co. No. 1, encountered the San Andres at 638 feet, immediately below the Trinity sandstone. The base of the upper division and top of the lower, was found at 1,200 feet. The base of the San Andres is near 1,700 feet. This limestone bank is San Andres in age, because it can be traced through many drill holes into Irion County, thence into the outcrop of the El Reno in Tom Green County. *Parafusulina rothi,* identified by Skinner, was found at 798, 818, 838, 908, 918–28, 1,078, and 1,108 feet. *Parafusulina sellardsi* was reported from 1,674 to 1,690 feet.

In the Big Lake oil field, the Big Lake's University No. 1, Skinner reports Word fusulines from the extreme top of the San Andres, at 2,973 feet. Additional ones were found at the following depths: 3,000–3,017; 3,017–3,035; 3,085–3,093; 3,102–3,114; and 3,126 feet. The upper division of the San Andres in this well is calcareous and contains numerous beds of intercalated sandstone.

[31] F. B. Plummer and Gayle Scott, "Geology of Texas, Vol. III, Upper Paleozoic Ammonites and Fusulinids, Pt. 1, Mississippian, Pennsylvanian and Permian Ammonites," *Univ. Texas Bur. Econ. Geol. Bull. 3701*, p. 304.

Fusulines, identified by Roth, as shown by Mohr,[32] in the Stanolind's Williams well No. 1, Irion County, from 1,220 to 1,235 feet, are reported in the lower Word of the Glass Mountains and in the two lower divisions of the Delaware Mountain group. This zone, the writer believes is in the upper part of the lower division of the San Andres.

In the Humble's Eubank No. 1, Gaines County, Skinner found *Parafusulina rothi* in the San Andres, about 675 feet below its top.

At numerous localities on the Central Basin platform, and north of it, Word and Delaware fusulines have been found in the San Andres at various depths, and *Parafusulina rothi* has been found from 300 to 400 feet below the Whitehorse group in the Seminole pool of Gaines County.

Fossils found in a core of limestone from 5,105 to 5,017 feet, just above the "Holt pay" in the Sinclair-Prairie's Holt No. 3 of the North Cowden pool of Ector County (well drilled since stereograms were completed), were identified by Carl O. Dunbar as *Parafusulina fountaini* and *Dictyoclostus bassi* McKee (*Productus ivesi* of authors, not Newberry). The core was taken about 1,000 feet below the top of the San Andres. *Parafusulina fountaini.*[33] has been found only in the Victorio Peak limestone, which is the upper member of the Bone Spring limestone. *Dictyoclostus bassi* McKee is also a characteristic brachiopod of the Leonard series. This information, which was made available to the writer very recently, strengthens the belief that the "Holt pay" is in beds of Leonard age and the overlying black shale and limestone beds are Guadalupe in age.

Skinner reports the fusuline *Schubertella melonica* from the upper Clear Fork limestone, just below the San Angelo, in the Humble's Lewis-Wardlaw No. 1, western Tom Green County. A zone about 250 feet below the top of the Hess limestone in the Glass Mountains, is characterized by this fusulinid.[34] Although the range of this fossil is not definitely known, it is present just below a conglomerate in both areas, and in beds believed by the writer to be time equivalents.

To justify the presence of Word and Delaware Mountain fusulines in beds below the Whitehorse group, some geologists believe that a series of beds occupy the interval between the San Andres and the Whitehorse. Dickey[35] suggests that because the San Andres at its type locality is only 500 feet thick and the fauna suggests its correlation with the Leonard, there may be a division within the group in the

[32] C. L. Mohr, *op. cit.*, p. 1697.

[33] Carl O. Dunbar and John W. Skinner, *op. cit.*, p. 675.

[34] Carl O. Dunbar and John W. Skinner, *op. cit.*, p. 586.

[35] Robert I. Dickey, *op. cit.*, p. 43.

Guadalupe Mountains where it is much thicker. From this study it appears that the San Andres group, as well as its time equivalents, is separable into an upper and lower division, over a wide area. It has also been suggested by Mohr that the fauna of the lower Word is closely related to the Leonard, and a break may occur within the Word. Further evidence of this break may be seen in the northeastern Glass Mountains, in the line of delineation between the limestone facies of the lower Word and the dolomitic reef facies of the Vidrio.

As previously shown, the authorities on paleontology are not in agreement as to the age of the *Perrinites* in the El Reno on the east rim of the basin, but if they are accepted unequivocally as Leonard, their presence can not be explained by the presence of a break within the San Andres or Word. This ammonoid is present in the upper division, or that part of the group above the San Angelo. In the same division, in the Midland basin and on the Central Basin platform, *Parafusulina rothi*, the characteristic fossil of the Guadalupe series, is found.

There is no evidence of which the writer is aware, that the sea withdrew from the South Permian basin at the close of Leonard time. That a brief hiatus appears on the east, south, and west rims of the basin is indicated by the conglomerate and overlap found in those areas at the beginning of San Andres time. It is further indicated by every well drilled deep enough to pass through the San Andres, in the South Plains area, that the highlands which in Leonard time furnished clastics for the Yeso and Clear Fork, were covered by the sea, and those of Guadalupe time were situated in other areas. The source of sediments in the south end of the basin was apparently the same during both Leonard and Guadalupe deposition, and the deeper sea lay in that part of the basin. Consequently sedimentation and fauna should have been affected less in the southern part of the basin, and it is believed, by the writer, that a gradual change in genera and species should be found there, which would range from the Leonard up into the Guadalupe. In such areas a conglomerate, which represents a hiatus of some magnitude, should, the writer believes, be used to bound a period of deposition if one be present near a faunal change. Thus the conglomerate below the present base of the Word should be made the base of that formation. Since in the Glass Mountains, *Perrinites* is known to occur above the conglomerate, its presence in the El Reno and the San Andres (if it is agreed that the ammonoids of these groups are Leonard forms) could be explained as being Leonard "holdovers." Likewise the Leonard aspect of the fauna in the lower Word, and the San Andres at its type locality could be explained.

If these criteria are not accepted and the San Andres is still held to

be of the Leonard series, because a few ammonoids of controversial age have been found in the San Andres and the El Reno in three widely separated localities, then the advanced forms of *Parafusulina,* which were supposedly characteristic of the Guadalupe series as distinguished from the Leonard, cease to be of any stratigraphic significance. These fusulines which are found in great numbers and are so widespread through the Delaware Mountain group and the various facies beyond, are found many hundred feet below the top of the limestone series, which on the shelf areas is situated between the Whitehorse group and the Yeso. This series of rock is surely the San Andres group. Likewise the fusulines found 1,000 feet below the top of the San Andres in the North Cowden oil pool, which are known only from the upper member of the Bone Spring limestone, cease to be of any importance. Thus the fusulines in several thousand feet of section of the Leonard and Guadalupe series, at the proposed type locality for the classic Permian section of North America, would be eliminated as significant stratigraphic time markers, and other fossils must be used to replace them.

SUMMARY OF SAN ANDRES DEPOSITION

With the close of the Leonard series there was cessation of deposition on the higher structural margins of the east, south, and west rims of the South Permian basin. Except in the southern environs of the basin, the influx of clastics during Guadalupe time was from directions different from those of the preceding period, and wide distribution of sand began. Subsidence of the Delaware and Midland basins, and the Sheffield channel, was accelerated, and the west limb of the Eastern platform and the Bone Spring flexure were formed.

In the Delaware basin the sandstones of the Brushy Canyon and the sandstone and limestone beds of the Cherry Canyon, were deposited. The sediments of these formations extended through the Sheffield channel into the Midland basin. Against the Bone Spring flexure and the north end of the Eastern platform the Brushy Canyon disappears by overlap and the Cherry Canyon comes to rest on the Leonard. In western Tom Green County the Brushy Canyon thins and interfingers with the San Angelo.

Beyond the Delaware basin to the north and east, the Cherry Canyon becomes dolomitic. It appears to merge with the limestone bank extending from Howard County into Crockett County and is present in the upper part of the limestone bank of the Fort Lancaster platform. In this division variable quantities of sand are found in the Sheffield channel and far to the north in the Midland basin. Seemingly

during this period the Vidrio reef and the Cherry Canyon reef formed.

Dolomite formed over the Central Basin platform during Brushy Canyon and Cherry Canyon time. Northward in the San Simon syncline and the Midland basin these two formations grade into a lower limestone and upper dolomite division which extends in a broad arc from one structural low to the other, just north of the Central Basin platform. These two divisions comprise the San Andres group in the South Plains area. Northward they grade into salt and anhydrite.

From the limestone bank of the Midland basin, the upper and lower divisions of the San Andres group grade eastward into the red clastics of the El Reno. The San Andres limestone of the Fort Lancaster platform and the Word formation grade southward into dark siliceous sandstones and siliceous shales.

Except where represented by evaporites, the San Andres and its time equivalents, the lower two divisions of the Delaware Mountain group, the Word, and the El Reno group are separable into an upper and a lower division over a wide area in the South Permian basin.

Many hundred feet of the upper El Reno were cut out by the Whitehorse overlap, but throughout the South Permian basin the San Andres or its time equivalents appear to be overlain by the Whitehorse group or its equivalents, except where the latter has been removed by erosion. The Whitehorse time equivalents are characterized by the fusuline, *Polydiexodina.*

Parafusulina rothi and *P. sellardsi,* which are characteristic fossils of the Guadalupe series of the Delaware basin and the Glass Mountains, are found in numerous localities in various facies of the San Andres group. From the writer's study it appears only natural that these fusulines should also characterize the San Andres.

A sharp line of delineation can not be drawn in the Glass Mountains, separating the Leonard from the Word on their faunal content. If the boundary of the two formations be lowered to the conglomerate resting upon the Hess limestone, then *Perrinites,* which has been generally recognized to range no higher than the Leonard, is found in the Word. The fauna of the lower Word, and the San Andres at its type locality, which resembles that of the Leonard very closely, would be regarded as Leonard "holdover" fossils.

This purely physical stratigraphic subsurface study, which was later corroborated by paleontology, indicates that the base of the Guadalupe series should be drawn at the base of the San Andres-El Reno groups, instead of at their top.

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EDNA GAS FIELD, JACKSON COUNTY, TEXAS[1]

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ABSTRACT

The Edna gas field, Jackson County, Texas, was discovered in 1919 by means of surface geology. Eighteen tests were drilled between 1921 and 1932, eight of which were completed as gas wells at depths between 2,600 and 4,100 feet, in formations ranging in age from Oakville to "Frio."

Deeper development in the years from 1932 through 1938 found gas at depths ranging from 4,600 to 5,400 feet, in formations ranging from lower Catahoula ("Frio") to *Textularia warreni* (Vicksburg) in age.

Twenty-five tests were drilled during the entire period of 1921–1938, during which time fifteen gas wells were successfully completed. Of the latter group five wells are now producing, all from the "Frio" between 4,600 and 5,000 feet. The deepest test drilled to date, the Steinberger Petroleum Corporation's Drushel No. 1, penetrated the lower Jackson at a total depth of 7,170 feet in 1937.

A pronounced sand inlier and wooded area of about 6,000 feet diameter marks the topographic character of the field. The subsurface structure is apparently a relatively flat, closed domal feature with a closure in excess of 100 feet although the exact amount of closure is still unknown. About 4,000 acres are considered to lie within the total area of probable closure but only 600 acres may be designated as productive to date.

Gas production to the present time amounts to approximately 10 billion cubic feet. The present relatively undeveloped state of the field precludes any definite estimates concerning future reserves.

INTRODUCTION

Recent developments in Jackson and Victoria counties of South Texas have focussed attention on a number of oil and gas fields in these counties which heretofore have been given little detailed geologic study.

The Edna gas field in Jackson County is one of these.

The present paper is an attempt to present some of the geologic data derived from operations in the field at the present stage of development.

ACKNOWLEDGMENTS

The writers wish to acknowledge the worthwhile suggestions of a number of geologists with whom the geology of the Edna gas field has been discussed informally, and particularly, their indebtedness to R. L. Beckelhymer, Marcus A. Hanna, M. C. Israelsky, and Sidney A. Judson for helpful criticism of the manuscript.

LOCATION AND TOPOGRAPHY

The Edna gas field is approximately 7 miles northwest of the town of Edna, Jackson County, Texas, adjacent to the west bank of the

[1] Manuscript received, September 24, 1940.

[2] Consulting geologist and paleontologist.

[3] Geologist; Steinberger Petroleum Corporation.

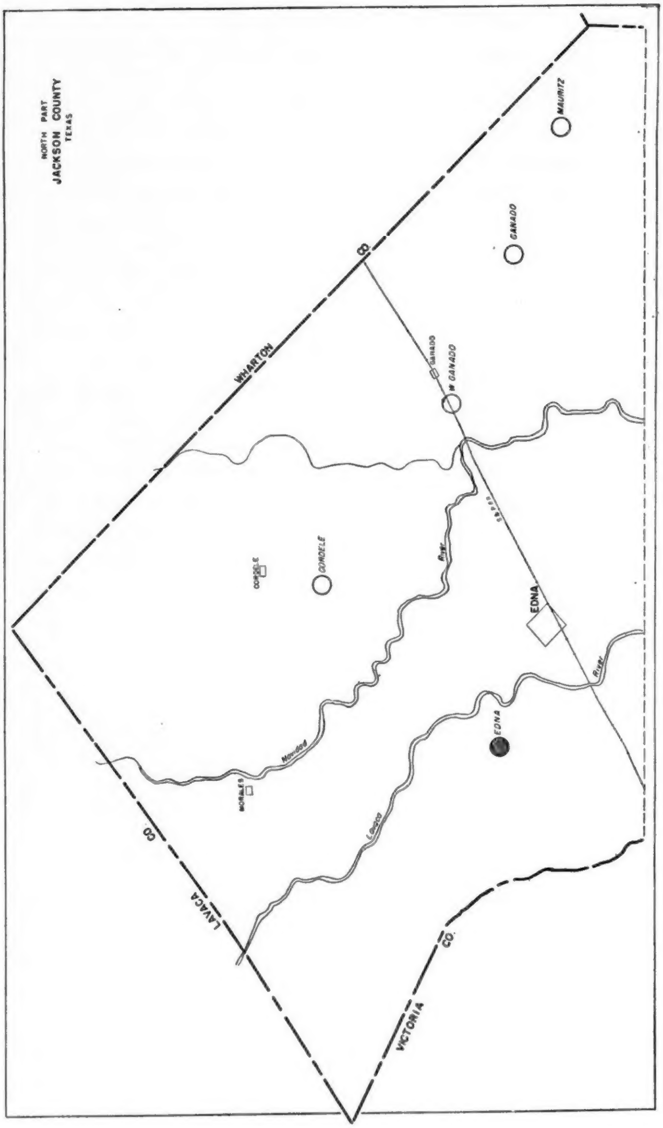

FIG. 1.—Regional map showing location of Edna gas field.

Lavaca River and in the area that includes the lakes locally known as the Horseshoe, Alligator, and Blackberry lakes.

The terrane slopes southward, breaking rather sharply eastward into the Lavaca River bottom. Topographically, the field is strikingly marked by the small lakes and several ovate sand ridges trending north and south; these ridges have a maximum relief of 10 feet. Horseshoe and Alligator lakes are near the center of the field area. Most of the adjacent land is heavily wooded and in places covered with a dense growth of underbrush. Flanking the wooded area is cultivated black clay land on which cotton and corn are raised. This black clay soil contrasts sharply with the soil in the field area which is composed almost entirely of sand.

HISTORY

As early as 1909 gas seepages were noted along the Lavaca River near the present field; these, together with the topographic features, suggested the possibility of the existence of oil or gas. In 1919, S. G. Drushel of Edna, Texas, wrote a report on the area and later was instrumental in assembling leases on which C. A. Wright and associates drilled the first well in 1921, located in Lot 6 of the Gale Subdivision of the Hays Ranch, F. Rodriguez Survey. This well was drilled to a depth of 2,670 feet where it blew out and the hole was lost. The same operators moved 125 feet east for their second test and succeeded in reaching a depth of 4,019 feet before a blow-out junked the hole.

Development in the area lagged until 1926 when C. A. Wright *et al.* completed the Drushel No. 3, located approximately 1,200 feet west of the other two wells, as a commercial gas well in a sand at 2,650 feet. Gas from this well came into Houston through a line then owned by Moody-Seagraves interests (now owned by the United Gas Corporation). The well was relatively short-lived, lasting only a few months, but it proved the existence of gas in commercial quantities and led to additional development in the area.

C. A. Wright *et al.*, who operated as the Jackson County Oil Syndicate and later as the Chicago Gulf Corporation, drilled approximately fifteen wells in the field between 1919 and 1932, eight of which were commercial gas wells in sands varying in depth from 2,600 to 4,100 feet. The other wells were failures either because of blow-outs or mechanical difficulties. During this period the Houston Oil Company drilled three shallow wells in the area in an endeavor to extend production, but without success. In 1932–1933, the Chicago Gulf Corporation attempted to make a deep test of their Drushel No. 10, located in Lot 14 of the F. Rodriguez Survey. This well was drilled to

6,425 feet where it reportedly ran into heaving shale. The operators plugged back to sand encountered at 5,367 feet and completed the test as a gas well that sprayed an estimated 5 barrels of 39° gravity oil per day.

The showing of oil in this well, together with the definite evidence of subsurface structure, led the Steinberger Petroleum Corporation to acquire leases in 1936 for the purpose of drilling a deep test. In accordance with this program their first well, Drushel No. 1, located in Lot 6 of the F. Rodriguez Survey, was drilled to the depth of 7,170 feet. Due to trouble with heaving shale, an attempt was made to complete this well in sand logged at 7,146–7,155 feet, but loss of tools during the process of drilling plugs resulted in an unsuccessful fishing job. The well was then plugged back and completed as a gas well through casing perforations at 4,637–4,650 feet.

Subsequent operations by Steinberger Petroleum Corporation resulted in the completion of four additional gas wells in the field, one of which was lost through a blow-out in the early part of 1938. All of these wells were completed at depths of less than 5,000 feet. During the latter part of 1938, the Dale Oil and Gas Company entered the field and drilled one well, located in the southeast corner of Lot 19, N. Rodriguez Survey, which was completed as a gas well in sand at 4,790–4,800 feet.

Stratigraphy

The geological formations found in the Edna gas field are the same as the beds found along the Vicksburg trend in southwest Texas. For subsurface considerations no attempt is made to establish correlations at the present time above the *Discorbis* zone. Common practice has been to commence collecting well samples just above this zone and to depend on electrical well logs for information concerning the geologic section above the *Discorbis* level.

Discorbis zone.—The *Discorbis* zone consists chiefly of olive-green shales, here and there with streaks of light gray, extremely fine sandstone. The updip foraminiferal assemblage common to this zone is present at Edna.

Heterostegina zone.—The *Heterostegina* zone, with a thickness of almost 100 feet, reverses the lithologic conditions of *Discorbis* time, consisting of sands and sandstones, with a few shale breaks. The top of this zone is well indicated in electrical well logs and also in the well cuttings.

"FRIO"

Immediately below the *Heterostegina* zone are sediments assigned

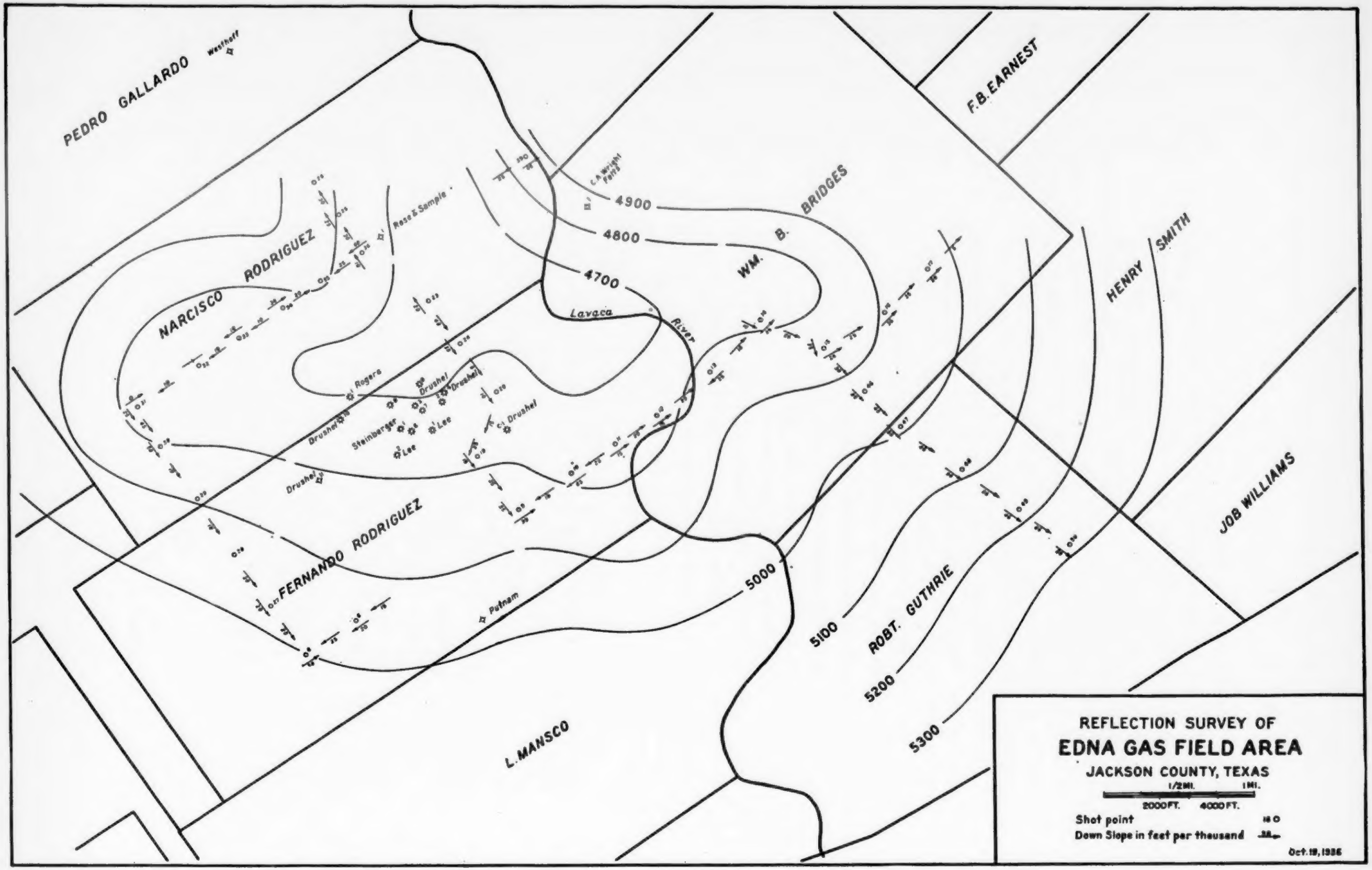

FIG. 2.—Reflection survey of Edna gas-field area.

to the "Frio"[4] formation inasmuch as the Edna gas field lies just north of the wedge of strata characterized by *Marginulina idiomorpha* as shown by Deussen and Owen.[5] The uppermost bed includes a well defined 40-foot thickness of fine to coarse, milky white quartz and dark chert sand, well defined on electrical well logs and readily identified in well cuttings under the microscope. Below this upper sand body occur beds of sand of lesser thickness intercalated with blue-green shales attaining a total thickness of about 1,200 feet.

Although predominantly non-marine in this area, the "Frio" contains two thin local fossil zones, as revealed by the Steinberger Petroleum Corporation's S. G. Drushel wells No. 1-C and No. 1. The first fossil zone, topped at 3,922 and 4,040 feet, respectively, contains a dwarf molluscan faunule with brackish-water Foraminifera and lignite. The second fossil zone, topped at 4,200 and 4,314 feet, respectively, contains a *Chara* spore-case faunule accompanied by thin pelecypods and streaks of lignitic shale. Other than these local occurrences and a few streaks of lignite, the "Frio" exhibits a terrestrial, non-fossiliferous facies.

TABLE I

STRATIGRAPHIC COLUMN, EDNA GAS FIELD
SUBSURFACE ZONATION

Formation	*Foraminiferal Zone*
Oakville	
"Catahoula"	
Marine wedge	*Discorbis* *Heterostegina*
"Frio"	
Lignitic shale	*Ammobaculites* *Textularia warreni* *Cyclammina*
Whitsett	*Uvigerina-Marginulina* *Massilina pratti*
McElroy	*Textularia hockleyensis*
Caddell	*Textularia dibollensis*

All nomenclature is local.

Marginulina idiomorpha, et cetera of the "Marine wedge" did not extend as far north as Edna gas field.

"Lignitic shale," *Ammobaculites, Textularia warreni*, and *Cyclammina* are commonly included by usage in the Vicksburg group of South Texas.

The Whitsett, McElroy and Caddell formations are subdivisions of the Jackson group.

Lignitic shale zone.—Immediately underlying the "Frio" is a more or less definite lignitic shale zone, sometimes referred to as "Vicks-

[4] The term "Frio" is used with quotation marks following F. B. Plummer, "The Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bull. 3232* (August 22, 1932), pp. 703 *et seq.*, Fig. 47.

[5] Alexander Deussen and Kenneth Dale Owen, "Correlation of Surface and Subsurface Formations in Two Typical Sections of the Gulf Coast of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1603–34, Fig. 1. (Special reprint for Schlumberger Well Surveying Corporation. Original paper did not include limits of paleogeographic seas.)

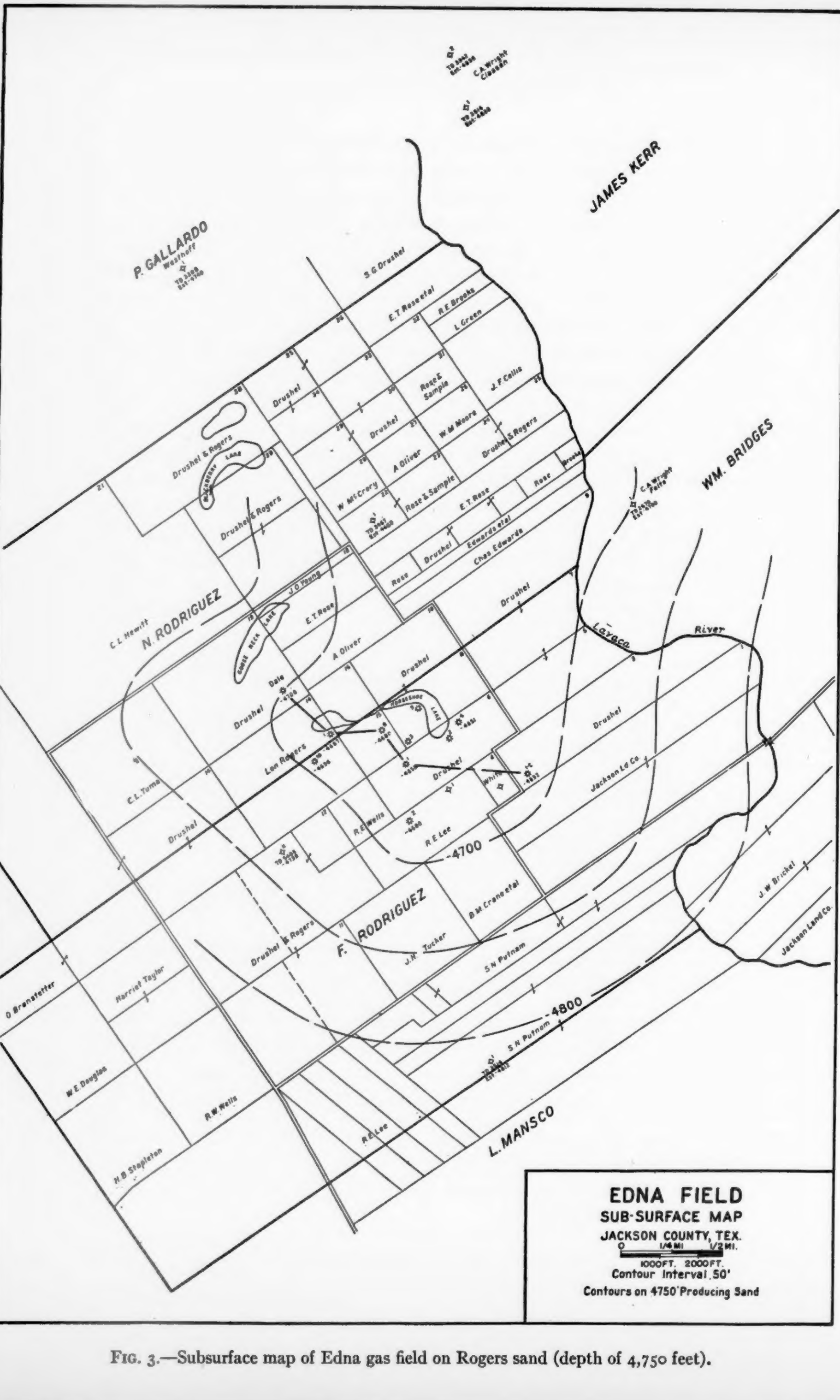

FIG. 3.—Subsurface map of Edna gas field on Rogers sand (depth of 4,750 feet).

burg." This zone occurs at a depth of about 5,000 feet in the Steinberger's Drushel No. 1. The cuttings are characterized by dark gray lignitic shale which persists commonly in the well cuttings from greater depths. Near the lower part of this section occur brackish-water, foraminiferal beds containing *Ammobaculites* and *Elphidium*. The entire zone is approximately 400 feet thick and includes some prominent sand bodies alternating with dark gray lignitic shales. The sand elements are the third series of thick sand bodies from the top of the *Heterostegina* zone, the second series occupying the top of the "Frio" formation.

VICKSBURG

Textularia warreni zone.—The *Textularia warreni* zone is the first definite marine section of any importance below the *Heterostegina* zone and is found as high as 5,340 feet. It includes a distinctive sand horizon at the top of the zone, although the remaining part of the section is predominantly shale. This sand is light gray in color, is streaked with lignite, and contains poorly preserved pelecypods. Under the microscope the sand is seen to be very fine to very coarse in texture, consisting of milky white quartz and dark chert. Fossils, other than pelecypods and lignite, include rare fish bones and rare black magnetite-speckled *Textularia warreni*. The top of this zone is difficult to establish accurately without core material, as the well cuttings alone fail to disclose the sand.

The remaining part of the geologic column at the Edna gas field is determined only from well cuttings inasmuch as no complete electrical well logs were run below the *Textularia warreni* zone. The *Textularia warreni* section in the Steinberger Petroleum Corporation's S. G. Drushel well No. 1 ranges from 5,340 feet to 5,994 feet, the latter depth being the top of the *Uvigerina-Marginulina* zone of the Whitsett-Jackson formation.

Below the sand at the top of the *Textularia warreni* zone the beds change to dark gray lignitic shale intercalated with a few light gray coarse sands and gray limestone streaks. Fossils include a large and varied foraminiferal and molluscan faunule typical of this zone elsewhere.

Cyclammina zone.—At 5,755 feet in the S. G. Drushel well No. 1 the *Textularia warreni* zone is characterized by an increase in size and abundance of Foraminifera and Mollusca. *Cyclammina* sp. appears in the *Textularia warreni* zone for the first time. The *Cyclammina* zone is a very useful local marker to indicate the lower part of the *Textularia warreni* zone.

JACKSON

WHITSETT FORMATION

Uvigerina-Marginulina zone.—The *Uvigerina gardnerae-Marginulina cocoaensis* zone of the Whitsett formation of the Jackson was encountered in the S. G. Drushel No. 1 at 5,994 feet. Lithologically, the Whitsett shales are lighter in color and less lignitic than the dark gray lignitic shales of the *Textularia warreni* zone. The *Uvigerina-Marginulina* zone is about 150 feet thick.

Massilina pratti zone.—At 6,145 feet in the S. G. Drushel No. 1 the *Massilina pratti* zone makes its appearance, also in the Whitsett formation, with little lithologic change. However, this zone contains a more varied and abundant foraminiferal faunule than any other part of the formation. The thickness of this zone is approximately 90 feet, making a total of 240 feet for the entire Whitsett formation.

McELROY FORMATION

Textularia hockleyensis zone.—Encountered at 6,232 feet in the Drushel well, the *Textularia hockleyensis* zone of the McElroy formation lithologically consists of predominantly marine shale with a few thin intervals of sand streaks and glauconite. Foraminiferally, the entire *Textularia hockleyensis* section defies differentiation except for a few zones of regional value for correlation purposes.

CADDELL FORMATION

Textularia dibollensis zone.—The first traces of *Textularia dibollensis* were found at 7,036 feet in the Drushel well, an interval of 747 feet from the top of the *Textularia hockleyensis* zone. However, glauconite, typical of the Caddell zone, occurs probably not lower than 7,000 feet, reducing the interval to 711 feet. Caddell lithology differs little from the McElroy except in more abundant glauconite. On the other hand, in foraminiferal character there is a marked change to the more varied and deeper-water facies of the Caddell fauna.

Lower zones.—Below the Caddell formation the geologic record, determined entirely from the Steinberger's S. G. Drushel No. 1 (the only well in the field to penetrate the Caddell), is fragmentary, due to difficulties in drilling through heaving shale. Cuttings obtained from this well below 7,100 feet showed no distinguishing features from those noted as Caddell except for a predominantly sandy phase from 7,145 feet to 7,170 feet, with one definite sand at 7,146–7,155 feet, and a bit sample at 7,170 feet containing sand with an oil odor. This zone suggests the Pettus horizon of the Cockfield formation, although the absence of *Nonionella cockfieldensis* in the well cuttings may leave

some doubt as to such a correlation. In view of the fact that such a condition is not uncommon in the uppermost Cockfield well cuttings of other areas, the lack of fossils is not significant.

Structural Geology

SURFACE

Although the writers have not attempted any detailed study of the surface beds of the Edna gas field area they are aware that earlier geologists reported evidences of structure based upon surface geology. The presence of an apparent sand inlier among predominantly clay type soils doubtless was the determining factor in such interpretations.

SUBSURFACE

Interpretation of the subsurface structure in the Edna gas field, even at this late date in its history, is still largely dependent on the correlation of drillers' logs, although seismograph-reflection shooting data now available give added weight to structural interpretations.

The key wells used in determining the structure are widely scattered except in the area of present gas production. North of the present gas-producing area four relatively shallow wells have been drilled which have a definite bearing on any broad interpretation of the structural conditions present. All of these wells were drilled prior to the advent of present methods of well-sample study and electrical well logging. The accurate correlations which can now be made between wells in the present producing area through the use of micropaleontology and electrical well logs contrasts sharply with well-to-well correlation northward. In that direction a possible extension of the structure may be assumed, based on the interpretation of drillers' logs.

Further development, particularly in the north area, may reveal greater structural relief than is now apparent. Faulting, which doubtless is present, will probably be defined by further drilling and will fit into a pattern typical of such structures. Contours drawn on the top of the 4,750-foot sand (locally given the name of Rogers sand) indicate a relatively flat, domal feature with a probable closure of 100 feet or more. None of the wells which indicate the possible northern part of the structure penetrated the Rogers sand; hence, interpolations were made from more shallow horizons to determine the datum at these locations. Contours have not been drawn in that part of the pool because of the uncertainty of correlations and the lack of geophysical data to support an interpretation of the structural conditions.

While there are not now any definite data on the origin of the Edna structure, it seems most logical to assume that the structural condi-

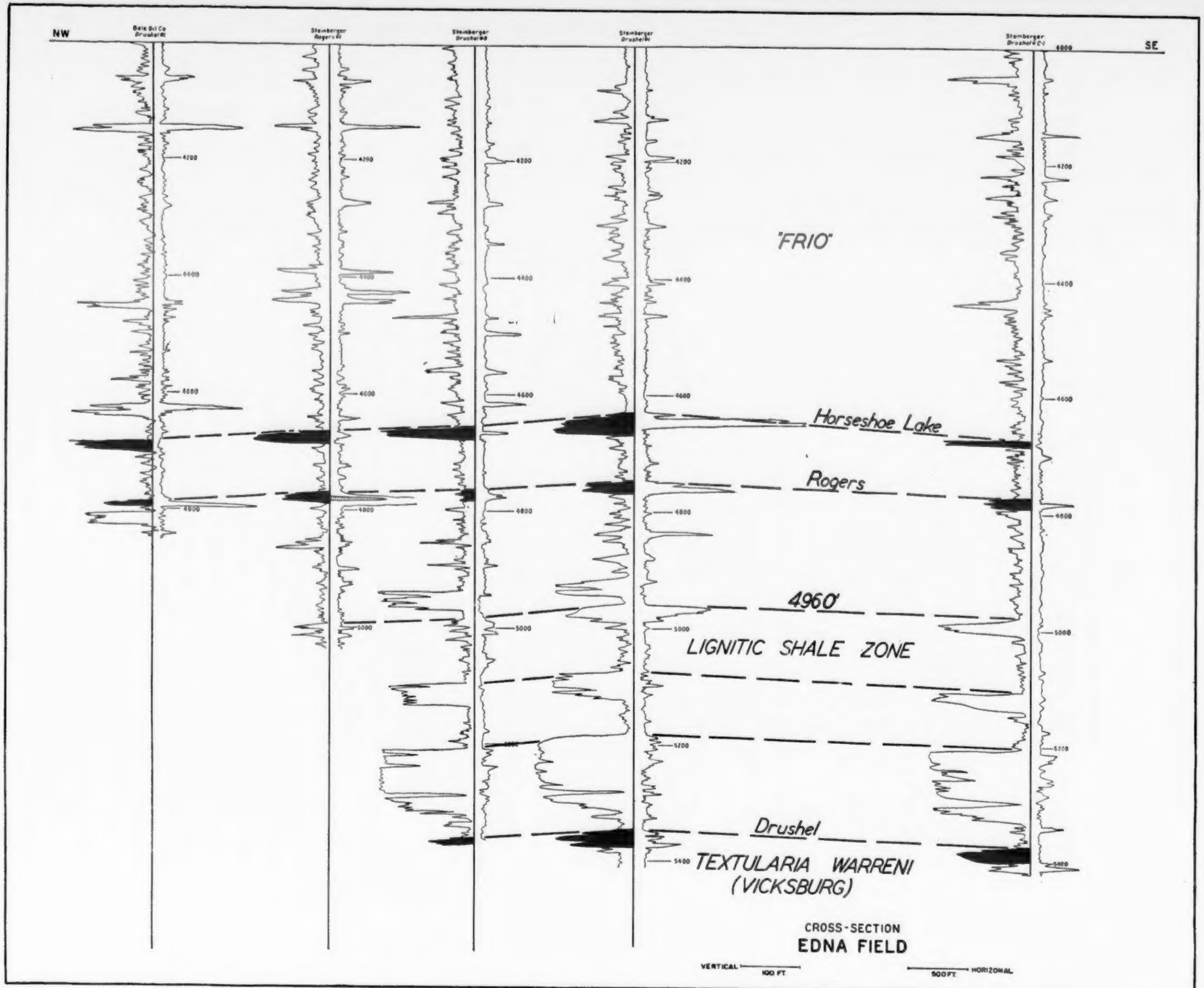

FIG. 4.—Electrical well-log correlations of Edna producing sands.

tions present are the result of a deep-seated salt plug. The faulting typically associated with structures of similar origin has not yet been proved at Edna although there are indications that a fault of major size may extend northeast-southwest across the northernmost limits of the structure. The structurally low dry holes, C. A. Wright's Classen No. 1 and Classen No. 2, and the Houston Oil Company's Westhoff No. 1, suggest the presence of such a fault. For the present, however, lack of control in key sectors precludes the incorporation of this possible fault in the structural picture.

Producing Sands

Wright sand.—Gas production was first developed in a zone at approximately 2,600 feet (probably basal Oakville) where a number of old wells had blow-outs which resulted in the tests being junked. This series of sands, herein designated as the Wright sand, consists of two or more sand lentils 5–15 feet thick, separated by shale and sandy shale of varying thickness. The individual sand members are not continuous over an extensive area and their exact correlation is practically impossible without the use of electrical well logs and uncertain even with their use. Just beneath this zone is a persistent sand bed which attains a thickness of 40 feet in some of the wells. This sand contains water wherever encountered in the field.

The lithologic nature of the Wright sand is not known as it has not been cored in the more recent wells and samples from the old wells are not available for study. Every well considered to be on structure has had showings of gas at this horizon and one of the old blow-outs (C. A. Wright's Drushel No. 2) was credited with a showing of oil in this sand.

It is interesting to note that these sands of the basal Oakville are either producing commercially, or have yielded good showings, both gas and oil, throughout the general strike area extending across Wharton, Jackson, and Victoria counties.

Heterostegina sand.—Other than the Wright sand, only the *Heterostegina* sand has yielded showings of gas in this field above the "Frio" formation. The *Heterostegina* sand occurs at approximately 3,560 feet and is a distinct and easily correlated unit, apparently continuous over the structural area. As yet no attempts have been made to produce from this horizon in the field.

"FRIO"

The first gas production from the "Frio" formation was obtained at approximately 3,850 feet and 3,955 feet. These sands are medium- to fine-grained and are interbedded with sandy shales and shales. The

thickness of the individual beds rarely exceeds 15 feet. The sand zone in general is continuous over the structure with individual layers lensing out from one location to another. Production from these sands has not been long-lived, and whether this is due to poor completion methods or to lack of initial gas reserves is not known.

Thin stringers of sand in the "Frio" from 4,105 feet to 4,470 feet contain gas and it is possible that they will provide gas in commercial quantity at some locations on the structure. These sands are rather hard, tightly cemented, calcareous sands and sandy limestones. The Chicago Gulf Corporation's Lee No. 2 produced for several years from a sand or sandy limestone at 4,105 feet in this zone.

Horseshoe Lake sand.—One of the persistent sands in the "Frio" formation (herein designated as the Horseshoe Lake sand) occurs in the field at approximately 4,640 feet. It is a medium- to fine-grained, hard, calcareous sand with no visible shale partings. The maximum thickness of the Horseshoe Lake sand is 30 feet, measured in the Steinberger's Drushel No. 1, the only well producing from this sand. In this well water occurs in the lower 15 feet of the sand with no evidence of an oil column between the gas level and the water level, the water level being established at a minus 4,564 feet. Locally, a thin gas-bearing sand is found below the base of the Horseshoe Lake sand with a 5–10-foot shale or sandy shale break separating the two sands. The lower sand was first noted in the Steinberger No. 1-C well.

Rogers sand.—The Rogers sand, occurring at approximately 4,755 feet in the field, is the next producing sand in the "Frio" formation. It is fine to coarse (in places soft) sand with local thin partings of sandy shale, and has a maximum thickness of 20 feet in the wells drilled to date. Wherever encountered on structure it has been gas-bearing. Thin lenses of water sand occur locally both above and below the Rogers sand, making necessary very careful cementing operations for proper shut-off on completion. No oil showings have been reported from the Rogers sand.

Other sands.—At approximately 4,960 feet in the "Frio" formation another fairly persistent sand occurs, which, though variable in thickness, appears to be continuous over the structure. Its maximum thickness was found to be 30 feet in the Steinberger's Drushel well No. 1. No cores have been taken from this level but from cuttings it appears to be medium- to coarse-grained, loosely cemented sand. Although untested, the electrical resistivity of the 4,960-foot sand in the Drushel No. 1 is comparable with the electrical resistivities of other producing "Frio" sands; hence it is assumed to have gas-bearing possibilities.[6]

[6] Since this paper was written the 4,960-foot sand has been brought into production in the Steinberger Petroleum Corporation's S. G. Drushel well No. 1.

The lateral limits of gas production from any one of the present producing sands of the "Frio" formation do not appear to be extensive, with the possible exception of the Rogers sand, which has not been defined in any direction. Production from the Horseshoe Lake sand, the upper "Frio" sands, and the unnamed 4,960-foot sand seems to be confined to the higher parts of the structure. However, the presence of many gas-bearing sand lenses throughout the entire "Frio" formation suggests accumulation of commercial quantities of gas in these sands as yet untested.

Oil possibilities.—Whether or not oil may be expected from the "Frio" formation in this field remains an unsolved problem. Recently, production of low-gravity oil has been obtained from a sand at or near the base of the formation near the town of Victoria, 25 miles southwest, and along the strike of the Edna gas field. This seems to indicate the possibility of oil production in the updip, non-marine facies of the "Frio" beds where proper structural conditions exist. Inasmuch as basal sands from this series occur in the geologic section at Edna, further development may reveal oil accumulation at these lower depths.

VICKSBURG (TEXTULARIA WARRENI ZONE)

Drushel sand.—Although there is a well developed sand at the 5,100-foot level in the Lignitic Shale zone (topped at 5,000 feet) no gas is found above the top of the *Textularia warreni* zone of the Vicksburg. Here a sand 10–25 feet thick (herein designated as the Drushel sand) is encountered in every deep well in the field at approximately 5,360 feet. The Drushel sand has been found in outpost wells both northeast and southwest along the strike of the field. This sand is shaly, medium- to fine-grained, sparsely fossiliferous sand with interbedded sandy shales and thin streaks of brittle shale. In the field the Drushel sand is found about 40–50 feet below the base of the Lignitic Shale zone and below a coarse, water sand which is persistent over the structural area. In the present producing area the Drushel sand contains water in its base with apparently no break between the water level and the gas- or oil-bearing part. The Chicago Gulf Corporation's Drushel No. 10 produced gas with some oil from the Drushel sand for several years and the same sand has yielded oil showings in the Steinberger's Drushel No. 1 and the Steinberger's No. 8 wells.

Lower sands.—At present little can be said about sands in the field encountered deeper in the geologic section. At 5,780–5,790 feet, near the base of the *Textularia warreni* zone, sand and sandy shale containing gas under high pressure were cored in the Steinberger's Drushel No. 1. This member is at present undeveloped. The sand at 7,146–

7,155 feet, encountered in the Steinberger's Drushel No. 1, of lower Caddell or upper Cockfield age, contained showings of gas which have not yet been tested.

Drilling and Development

Development in the Edna gas field has been restricted to an area of approximately 600 acres considered to be at or very near the top of the structure. Scattered wells outside this area and apparently on structure have been too shallow to be considered an adequate test of their respective location. According to seismic structural interpretation, approximately 4,000 acres may be considered as occupying a position within the area of closure.

Gas in apparent commercial quantities has been found in this field ranging from the Oakville to the *Textularia warreni*-Vicksburg formations. Such sands have been logged at the following depths: 2,600; 3,570; 3,850; 3,955; 4,105; 4,640; 4,750; 4,960; 5,360; and 5,780 feet. The sands above 4,200 feet were developed during the early history of the field within a restricted area. Development since 1936 has brought into production the sands from 4,200 feet to 4,900 feet and extended the producing limits of the field.

In October, 1936, the Steinberger Petroleum Corporation completed Drushel No. 1 in a "Frio" (Horseshoe Lake) sand at 4,637–4,655 feet, producing 35 million cubic feet of gas to establish definitely the lower sands of this part of the section as commercial producers. This well had initial pressures of 1,875 pounds on the tubing and 1,925 pounds on the casing when producing through $\frac{1}{4}$-inch choke.

The same organization opened the 4,750-foot (Rogers) sand in December, 1936, completing Drushel No. 10 at 4,790–4,820 feet with an open flow of 32 million cubic feet of gas daily. Producing pressures at the well were 1,875 pounds on the tubing and 1,925 pounds on the casing through a $\frac{1}{4}$-inch choke.

In February, 1937, a second well, the Steinberger's Rogers No. 1, was completed in the Rogers sand with an open-flow capacity of 67 million cubic feet with pressures of 1,850 pounds on the tubing and 1,900 pounds on the casing, when producing through $\frac{1}{4}$-inch choke. Two other wells are now producing from this sand with similar pressures but with smaller flow capacities.

Other than the production from the 5,360-foot (Drushel) sand originally obtained in the Chicago Gulf's Drushel No. 10, no gas withdrawals have been made from sands below 4,900 feet.

It has been the practice in the later wells drilled in the field to drill through all the sands to slightly below 5,400 feet, run 5–7-inch casing

to the bottom of the hole after having run electrical well surveys for sand records, and then gun-perforate for production. As several gas sands are recorded in each well drilled, the operators usually expect to produce from successive sands in each well as becomes necessary.

The cost of a completed well in the field is approximately $25,000. It is necessary to set 80–100 feet of 16-inch conductor pipe, 1,000 feet of $10\frac{3}{4}$-inch casing to shut off artesian-water sands encountered just above that level, and production string of 5–7-inch casing. Tubing strings have been 2-inch or $2\frac{1}{2}$-inch "upset" with two wells having a mixed string of 2-inch "upset" and $1\frac{1}{4}$-inch "upset." In the wells drilled early in the life of the field, screen was used but in the recently drilled wells no screen has been run. Christmas-tree connections are all 6,000-pound test. Each well produces through a 500-pound W.P. separator. A tank of 65–250 barrels capacity is erected to save the small amount of condensate produced with the gas.

The gas output of the field has been contracted for by the Houston Gulf Gas Company (subsidiary of the United Gas System) at a price of 5 cents per 1,000 cubic feet. Most of the gas now produced is brought eastward into the Houston area through this company's main trunk line from southwest Texas. The condensate produced with the gas is sold locally where it is used for tractor fuel.

Conclusion

In common with many of the older fields of the Gulf Coast region, outside the definitely established productive trends as now known, the Edna gas field has had only a limited amount of scientific development. The records of early wells are inadequate for present use but point to the possibility of a productive area greatly in excess of the present producing limits. It is believed that careful and extensive coring supported by electrical well logging will add a number of producing gas sands to the field and it is possible that oil sands will be uncovered in the section now considered to be solely gas-bearing. Improved completion methods and restricted flowing rates for the gas wells should lengthen the life of the individual wells considerably over that of the old wells which were subjected to heavy unrestricted withdrawals.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 1 (JANUARY, 1941), PP. 120-151, 8 FIGS.

GEOLOGY OF WIND RIVER MOUNTAINS, WYOMING[1]

E. B. BRANSON[2] AND C. C. BRANSON[3]
Columbia, Missouri, and Evanston, Illinois

ABSTRACT

The Wind River Mountains are made up of a core of pre-Cambrian granodiorites, except at the south end where schists predominate. On the northeast flank the dips of the sediments range from 10° to 15°. The dipping sediments range from Cambrian to late Cretaceous in age, only the Silurian being absent. Eocene, Oligocene, Pliocene, and Pleistocene overlap the older formations in some places. On the east side a series of anticlines parallels the main range about 25 miles from the summit.

Minor faults affect the anticlines as well as the main range on the east side and the pattern of the lakes indicates much faulting in the pre-Cambrian core.

The main uplift and folding of the range came at the close of the Mesozoic, but minor uplifts occurred during the Cenozoic. That the uplifts were irregular is indicated by the absence of Ordovician and Devonian strata at the south end, and the pinching-out, north of the range, of the Tensleep, Phosphoria, and Chugwater formations.

The Lander sandstone at the base of the Ordovician in the southern end of the Wind River Mountains is absent at the northern end and thickens to 80 feet or more on the east side of the Big Horn Mountains.

The glaciation and peneplanation of the range are worthy of more discussion than can be given in a short paper, and the development of the drainage lines east of the range should be treated at length.

The known oil-bearing formations on the east flank are Madison, Tensleep, Phosphoria, Dinwoody, Sundance, Dakota, Mowry, and Frontier.

INTRODUCTION

For several years the writers have been planning a comprehensive report on the geology of the Wind River Mountains. This paper is a summary of research to date and presents preliminary conclusions.

The senior writer did his first geological work in the Wind River Mountains in 1904 and has spent 14 summers working in them since that time. The junior writer has spent 10 summers on geological work in the Wind River Mountains and adjoining regions.

GEOGRAPHY

The Wind River Mountains are eroded from a northwest-southeast-trending anticline and lie entirely within the boundaries of Fremont County, Wyoming. The range is 150 miles long and about 40 miles wide; its maximum elevation is 13,800 feet and it rises above a general level of about 5,000 feet on the east, and 7,000 feet on the west. The largest town on the east side is Lander, and on the west side, Pinedale. United States Highway 287 extends along the northeast flank of the range. Wind River and its tributaries drain the north-

[1] Read before the Association at Chicago, April 12, 1940. Manuscript received, August 15, 1940.

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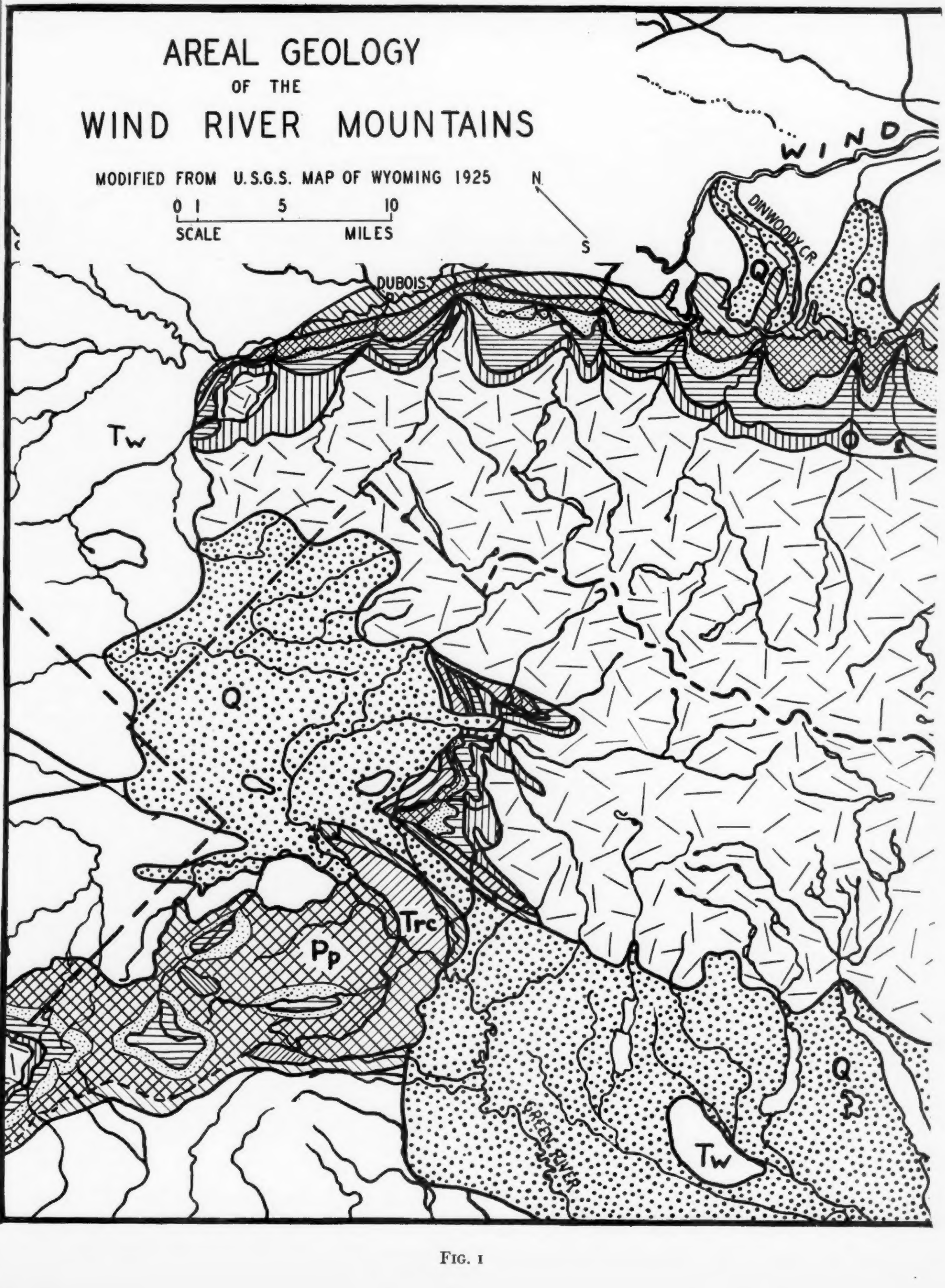
AREAL GEOLOGY
OF THE
WIND RIVER MOUNTAINS
MODIFIED FROM U.S.G.S. MAP OF WYOMING 1925
N
S
0 1 5 10
SCALE MILES
WIND
DINWOODY CR.
DUBOIS
Q
Tw
Pp
Trc
GREEN RIVER

FIG. 1

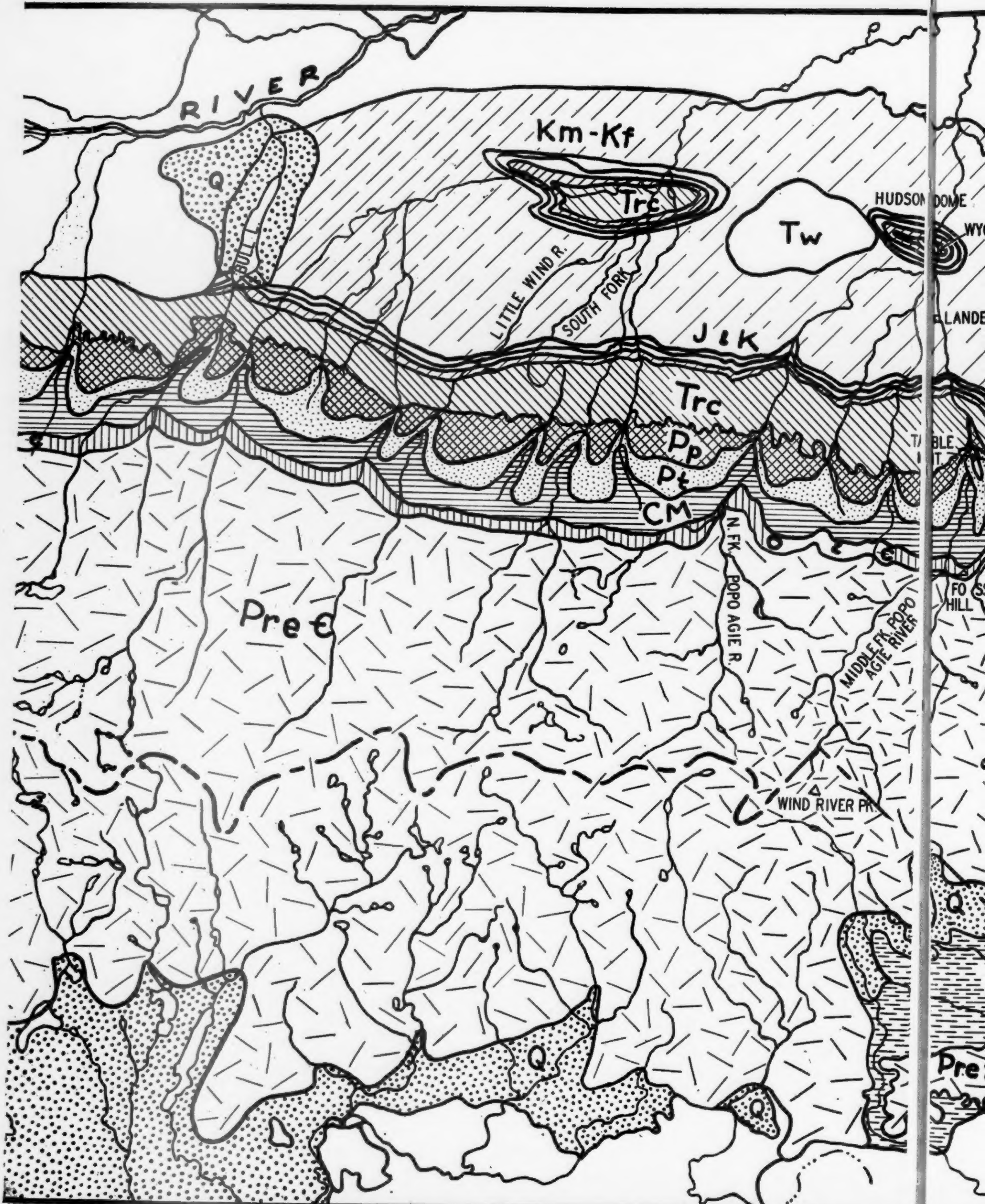

FIG. 1 (*continued*)

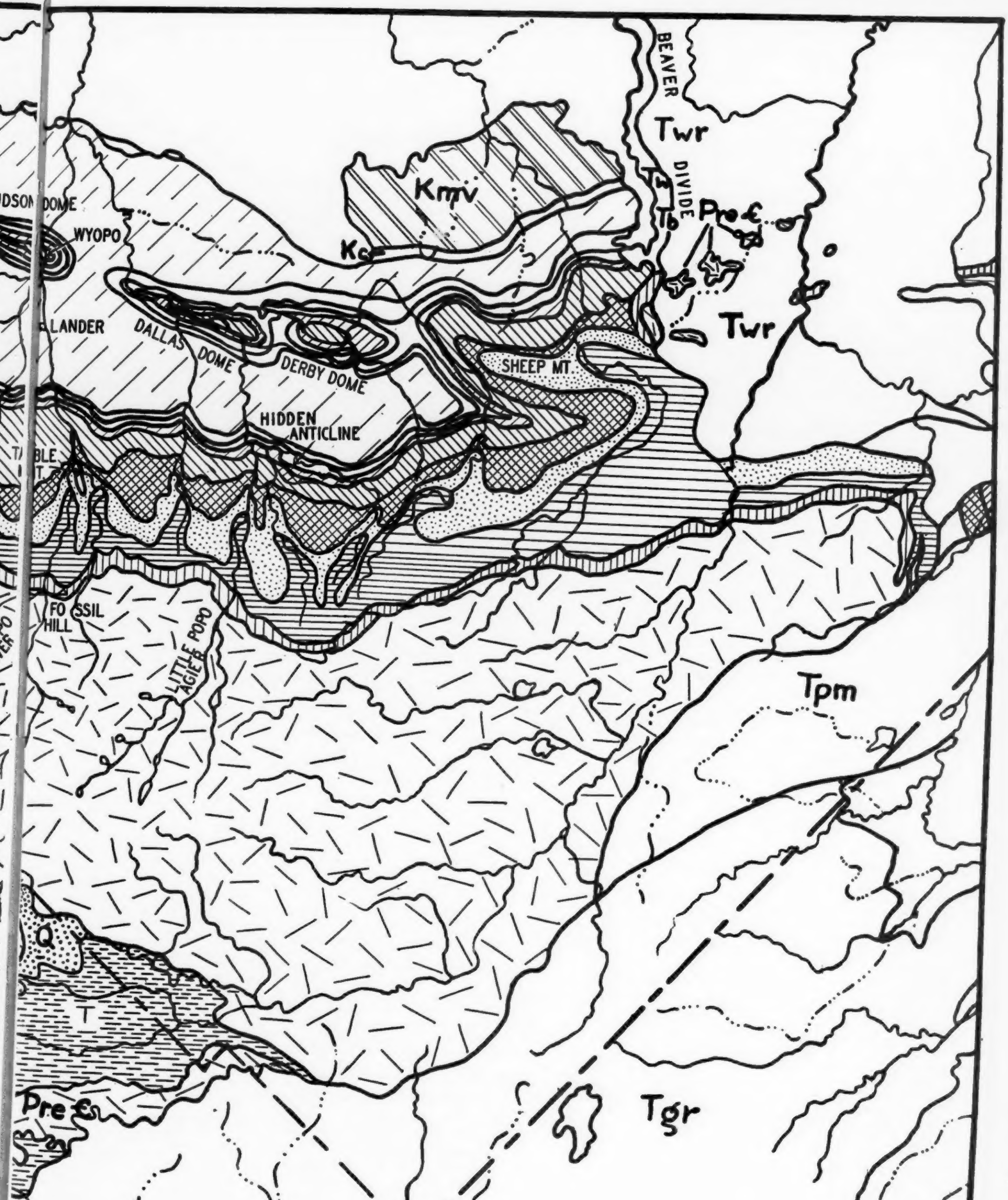

FIG. 1 (*concluded*)

TABLE I

FORMATION NAMES IN WIND RIVER REGION

	This Paper	*Sinclair and Granger (1911)*	*Condit (1924)*	*Bauer (1934)*	*Nace (1939)*
Pliocene	Burnt Gulch		Terrace gravels	Gravel terrace	
Oligocene	White River	L. Oligocene		Brule Chadron Sweetwater	Chadron Beaver Divide
Eocene	Uinta? Bridger? Wind River	Uinta Bridger? Wind River	Wind River Fort Union	Uinta Bridger Wind River Fort Union	Continental Pk. Bridger Wasatch
Cretaceous	.... Mesaverde Cody Frontier	*Woodruff (1911)* Mancos	Mesaverde Mancos	Lance Fox Hills Lewis Mesaverde Cody Frontier	
	Mowry			Mowry Thermopolis	
	Dakota	Dakota		Dakota	
	Cloverly	L. Cret.?	L. Cret.?	Fuson Lakota	
Jurassic	Morrison Sundance	Morrison Sundance	Morrison Sundance	Morrison Sundance	
Triassic	Gypsum Spring Wyopo Popo Agie Crow Mountain Alcova Red Peak	Chugwater	Chugwater	Nugget? Jelm Chugwater Alcova	
	Dinwoody	Embar	Dinwoody	Dinwoody	
Permian	Phosphoria		Phosphoria	Phosphoria	
Penn.	Tensleep		Tensleep Amsden	Tensleep Amsden	
Miss.	Sacajawea Madison		Madison	Madison	
Devonian	Darby		Darby	Devonian	
Silurian	Absent		Absent	Absent	
Ordovician	Bighorn Lander		Bighorn	Bighorn	
Cambrian	Gallatin Gros Ventre Flathead		Gallatin Gros Ventre Flathead	Gallatin Gros Ventre Flathead	

eastern side, Green River and its tributaries the southwestern side, and Sweetwater River the southern end and part of the southwestern side.

The range consists of a core of pre-Cambrian granodiorite and metamorphics on which the higher parts of the range and the glaciated peaks are developed. On the northeastern side Paleozoic sediments form foothills and some resistant beds support long dip slopes to the plains. Mesozoic sediments underlie hogbacks and valleys paralleling the axis of the range.

Stratigraphy

PRE-CAMBRIAN

The base of the stratigraphic section is the granite, which is presumably Archeozoic in age. It is normally pinkish and medium-grained, but there are gray colors and pegmatitic phases. Metamorphosed sediments antedating the granodiorite and intruded by it are unevenly distributed along the range. In the southern end they underlie a wide area and consist of chlorite schists, hematite schist, quartz-mica schist, quartzite, and other metamorphic rocks.

CAMBRIAN

Although the Cambrian rocks of the Wind River Range are made up of three distinct lithological types recognized as formations, there are no stratigraphic breaks within the series. The average thickness of the three formations is about 1,200 feet.

Flathead sandstone.—The oldest formation is the Flathead sandstone, a deep red sandy series which grades upward from arkosic conglomerate to sandstone and shaly sandstone. The basal conglomerate consists of chemically unaltered detritus from the underlying granite. The formation is 345 feet thick on the divide between Townsend Creek and Middle Fork of Popo Agie River. Some of the beds in every section are quartzitic. The formation does not form cliffs, but its lower members form slabby dip slopes which, because of the water-bearing character of the sandstone, are covered by pine forest. Fossils are rare in most members, but one light-colored fine-grained sandstone bed is crowded with specimens of *Dicellomus. Lingulepis* and *Lingulella* are found in some beds, unidentified impressions are abundant, and a few trilobite specimens have been collected. The formation is assigned to the Middle Cambrian because of its stratigraphic position below the Middle Cambrian Gros Ventre shale, and similarity of its fauna to that of the Gros Ventre. The fauna has not been studied adequately.

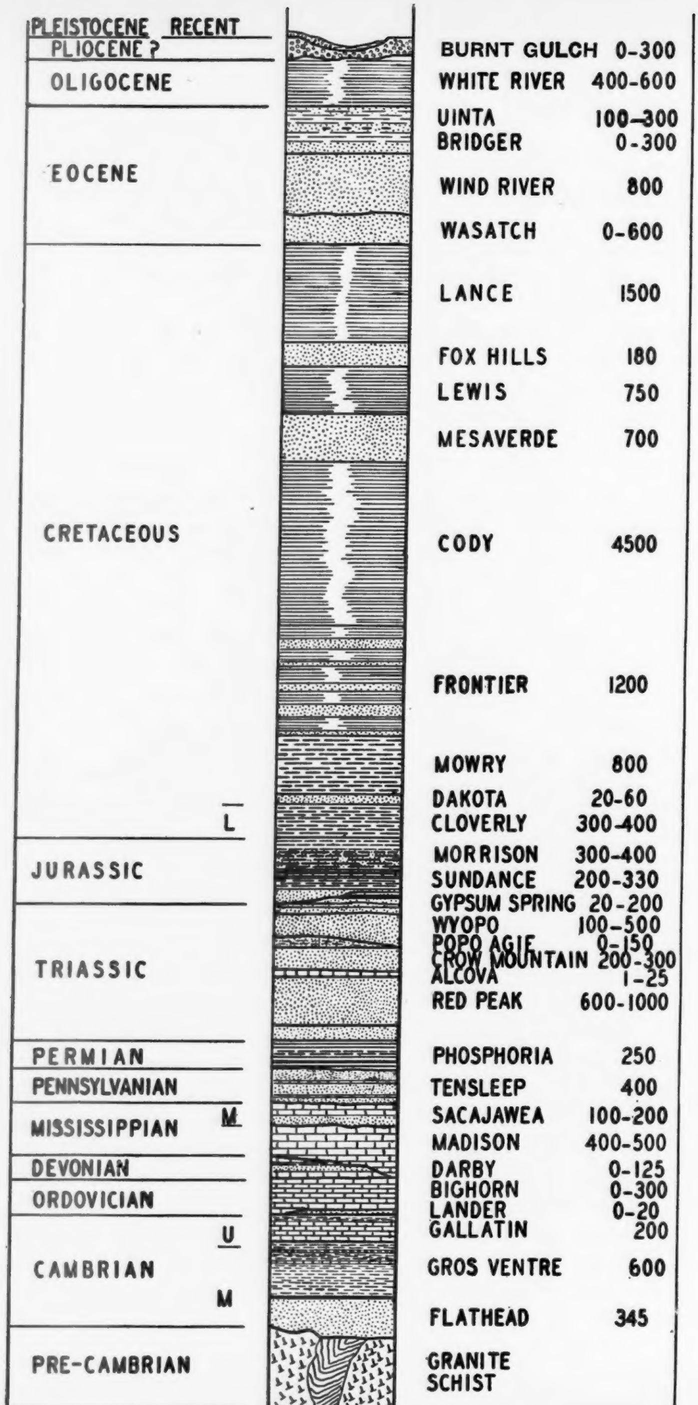

FIG. 2.—Columnar section of formations exposed in and near Wind River Mountains.

Gros Ventre formation.—The Gros Ventre formation is differentiated from the Flathead below entirely on lithologic grounds and the contact is drawn arbitrarily at the level above which shale is present in significant quantity. No disconformity was found by the writers. Along Middle Fork of Popo Agie River the red color of the Flathead continues up into the Gros Ventre. On South Fork of Little Wind River the basal part of the Gros Ventre consists of green sandstone beds mottled with red-brown spots alternating with light greenish micaceous shales. The main body of the formation is almost entirely of greenish micaceous shale, sandy micaceous shale, and sandstone. Near the middle of the formation a massive bed of dolomite 5 feet thick occurs on Fossil Hill, Middle Fork of Popo Agie River. On South Fork of Little Wind River and on the west side of Sheep Mountain a bed of greensand is associated with fucoidal sandstone. The greensand consists of rounded particles of pure glauconite with clear quartz filling the interstices of the grains. In the upper part of the formation there is a bed of limestone shingle conglomerate which is exposed in few places, but which may be seen in place on South Fork of Little Wind River. The total thickness of the formation is 400–500 feet.

Fossils are rarely seen, but phosphatic brachiopods were found in a dolomite and trilobites and hyolithids in a siltstone near the top of the formation on Sheep Mountain. The fauna has been determined by workers in other regions as being Middle Cambrian in age. The Gros Ventre shale weathers into a micaceous clay which forms no cliffs. It is expressed physiographically as steep grassy slopes constituting an open belt between the forests on the Flathead and the aspen and shrub thickets on the Gallatin. In many places the shale has slumped and slump terraces are common on the grassy slopes. A great rock slide on the north side of Bull Lake Creek was formed by movement in the Gros Ventre shales.[4]

Miller[5] proposed the use of Depass as a formation name in the Wind River Canyon and reduced Flathead and Gros Ventre to member rank. The writers find no justification for this change in either the Wind River Mountains or Wind River Canyon. They agree with Deiss[6] who says that "The need for the name Depass formation in the eastern part of the Owl Creek Mountains is not imperative."

Gallatin formation.—The basal boundary of the Gallatin formation is arbitrarily drawn at the bottom of a massive cliff-forming dolomitic

[4] E. B. Branson, "Bull Lake Creek Rock Slide in the Wind River Mountains of Wyoming," *Bull. Geol. Soc. America*, Vol. 28 (1917), pp. 347–50.

[5] B. Maxwell Miller, "Cambrian Stratigraphy of Northwestern Wyoming," *Jour. Geol.*, Vol. 44 (1936), pp. 123–24.

[6] Charles Deiss, "Cambrian Formations and Sections in Part of Cordilleran Trough," *Bull. Geol. Soc. America*, Vol. 49 (1938), p. 1102.

limestone and shingle conglomerate. No evidence of disconformity was found although Miller[7] states that he recognized locally a weak erosion surface in the northwestern part of the Wind River Mountains. The middle part of the formation consists of thin limestones, "pebbly" limestones in which there are rounded concretionary glauconitic grains, and oölites separated by thin bands of light green shale. This part of the section is well exposed in the hanging wall of a slump on the north side of Fossil Hill. Fossils occur in the oölites and in a crystalline limestone at the top of the calcareous series. The upper part of the formation consists of shales and sandy shales in which no fossils have been found. Shingle conglomerate beds occur throughout the lower part of the formation and there are some thin beds of this character in the middle part. These shingle conglomerates are composed of thin, flat pieces of dolomitic limestone with rounded corners. The limestone pebbles overlap one another and ordinarily are inclined to the bedding planes. The matrix is dense gray limestone and there is an admixture of greenish glauconitic material and of red iron-stained fragments. Slabs of the shingle conglomerate are resistant and furnish numerous blocks of float over the Gros Ventre shale slopes. Part of the Gallatin is exposed in ledges in many places, but good sections are scarce.

The fauna of the middle part of the formation is varied. Phosphatic brachiopods, carapaces of crustaceans, trilobites of many kinds, and columnals of cystoids (may be crinoids) are abundant. Study of University of Missouri collections has not been completed for publication. Workers in near-by areas have identified several Dresbach and Franconia faunal zones within the formation, but no useful fossils have been found in the upper part.

Columnar structures near the middle of the Gallatin have been found in many places along the northeast flank of the mountains. They seem to be near the same horizon in all of the places studied. They probably originated through mud cracking, differential solution, and pressure as described by Branson and Tarr.[8]

Deiss[9] proposed the name Boysen to replace Gallatin in Wind River Canyon. Although his reasons for discarding the name "Gallatin" may be valid the writers are retaining the long-used term.

ORDOVICIAN

In most of the Wind River Mountains the Ordovician is repre-

[7] B. Maxwell Miller, *op. cit.*, p. 119.

[8] E. B. Branson and W. A. Tarr, "New Types of Columnar and Buttress Structures," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 1149–56.

[9] Charles Deiss, *op. cit.*, pp. 1104–05.

sented by only one formation, the Bighorn dolomite, but the Lander sandstone occurs in the central part of the Wind Rivers and some geologists have attempted to differentiate the Leigh dolomite in the range.

Lander sandstone.—The shales at the top of the Gallatin are overlain in the south-central part of the range from north of Little Popo Agie River to Squaw Creek by a quartzitic sandstone, ranging from a few inches to 10 feet in thickness, which contains an extensive fauna dominated by *Orthoceratites*. The cephalopods were studied and the other forms provisionally identified by Miller[10] who considered them Richmond in age. A sandstone of like stratigraphic position, lithology, and fauna occurs on the eastern flank of the Bighorn Mountains. On North Fork of Crazy Woman Creek it consists of sugary white sandstone overlain by reddish coarse-grained sandstone grading into the overlying dolomite. *Maclurina*, *Cyclendoceras* and a large conodont fauna have been collected there.

Bighorn dolomite.—The Bighorn dolomite forms a prominent line of cliffs in the walls of the canyons and stands as castellated buttresses above the Cambrian slopes at the top of the dip slopes. It consists of massive light buff dolomite which weathers irregularly to a rough, pitted surface. The irregular weathering is due to textural differences.[11] The greatest thickness of the Bighorn is about 300 feet in the northern part of the range. It thins to about 200 feet in Fossil Hill and pinches out within 25 miles southeastward. Fossils are scarce and difficult to collect, but *Halysites* is reasonably common. No lithologic or faunal unit comparable with the Leigh dolomite member of the Gros Ventre Range has been recognized in the area. The fauna of the Bighorn dolomite is not recognizably younger than that of the Lander sandstone, although some species not found in the Lander are present in the Bighorn.

SILURIAN

Silurian strata are absent in the Wind River Mountains.

DEVONIAN

Darby formation.—The Darby formaton of the Devonian wedges into the Wind Rivers from the north and pinches out a short distance south of Middle Fork of Popo Agie River. It is well exposed on Dinwoody Creek, Bull Lake Creek, and in the canyon of South Fork of

[10] A. K. Miller, "The Cephalopods of the Bighorn Formation of the Wind River Mountains of Wyoming," *Trans. Connecticut Acad. Sci.*, Vol. 31 (1932), pp. 199–297.

[11] Eliot Blackwelder, "Origin of the Bighorn Dolomite of Wyoming," *Bull. Geol. Soc. America*, Vol. 24 (1913), pp. 607–24.

Little Wind River. At the latter locality it consists of dolomites scarcely distinguishable from the underlying Bighorn and of fish-bearing sandstones with shale beds between. One sandstone bed is crowded with plates of ostracoderms which make up about half of the volume of the rock. Good specimens have been collected from another sandstone bed about fifteen feet higher. Conodonts of the genera *Icriodus*, *Polygnathus*, and *Palmatolepis* have been found in a black shale on Bull Lake Creek. Study of the fish fauna has not been completed and the age can at present be limited only to Middle or Upper Devonian.

MISSISSIPPIAN

Two Mississippian formations are present and about half of the period is unrepresented. Seas came in early in the period and continued to lower middle Mississippian; the land emerged until late middle Mississippian when a sea advanced for a short time and then retreated to leave the region emergent through all or nearly all of the upper Mississippian.[12]

Madison limestone.—The Madison consists entirely of limestone and dolomite, the upper part crinoidal, the remainder light gray, compact, closely jointed, cherty in some layers. Fossils are numerous in the upper part, but good specimens are difficult to obtain. The common index fossil is *Spirifer centronatus* which is found in all parts of the formation. Abundant fossils occur in northwestern Wyoming and at some places in the Bighorn Mountains. Brachiopods are the most abundant fossils, crinoid columnals, and corals are common, blastoids are rare, fishes and plant remains have been found. The fauna is closely related to that of the Chouteau of Missouri and of the lower part of the Burlington. Members of the Madison have been differentiated lithologically in Montana, but no consistent members have been recognized in the Wind River Mountains.

The Madison limestone was exposed to weathering during most of the middle Mississippian and caves and sink holes were developed in it. On the south side of Bull Lake Creek above the lower falls a sink was developed into which a block of Madison slumped and the sink was filled around the block by mud of the succeeding seas.

Sacajawea formation.—The sea advanced over the area in late middle Mississippian time and deposited red shale and cherty lime-

[12] The writers use lower, middle, and upper Mississippian in preference to the various names that have been proposed for the groups in the Mississippi Valley. The tendency to introduce new series names and the inclusion in the Kinderhook of Devonian as well as Mississippian formations has destroyed the usefulness of the more elaborate groupings.

stone. In the upper part of the red shale there is abundant limonite and hematite, some in the form of buckshot ore. On Bull Lake Creek the common red shale is not present, but there is a lower red and yellow-brown sandstone breccia. Fossils are abundant in the limonitic part of the red shales in the southern part of the range and in the limestone of Bull Lake Creek. The larger fossils have been described by Branson and Greger[13] and by C. C. Branson[14] and the ostracods by Morey.[15] A conodont fauna was recently discovered and is being studied. Croneis and his students[16] have correlated the ostracod fauna with that of higher layers of the Chester, but such correlations are difficult because few ostracods have been described from middle and upper Mississippian. The conodont fauna is at present of little value in correlation for the same reason. These beds have long been included in the Amsden formation which was named by Darton from an essentially non-fossiliferous section in the northeastern part of the Bighorn Mountains. The Amsden of the type locality and of many other localities has been proved to be almost entirely Pennsylvanian in age although its lower part may be Mississippian. The lower part has yielded a conclusive fauna only in the Wind River Mountains and the junior writer has separated the Mississippian beds of that area from the higher Amsden and has named them the Sacajawea formation (pronounced sä-kä'jä-wā'-ä). On Bull Lake Creek 60 feet of laminated limestone without fossils lies with irregular contact on the Sacajawea and is overlain disconformably above. This sequence may constitute another formation, possibly of Chester age.

PENNSYLVANIAN

Tensleep formation.—The Pennsylvanian rocks of the Wind River area are a single sedimentary sequence, the Tensleep formation. They lie disconformably on the laminated limestones previously mentioned, and blocks of that limestone are incorporated into the lower beds of the basal sandstone of the Tensleep. The Tensleep formation consists predominantly of cross-bedded sandstone, but low in the formation there are beds of limestone alternating with sandstone and one se-

[13] E. B. Branson and D. K. Greger, "Amsden Formation of the East Slope of the Wind River Mountains of Wyoming and Its Fauna," *Bull. Geol. Soc. America*, Vol. 29 (1918), pp. 309–26.

[14] C. C. Branson, "Stratigraphy and Fauna of the Sacajawea Formation, Mississippian of Wyoming," *Jour. Paleontology*, Vol. 11 (1937), pp. 650–60.

[15] P. S. Morey, "Ostracoda from the Amsden Formation of Wyoming," *Jour. Paleontology*, Vol. 9 (1935), pp. 474–82.

[16] Carey Croneis and H. I. Funkhouser, "New Ostracodes from the Clore Formation," *Denison Univ. Bull., Jour. Sci. Lab.*, Vol. 33 (1938), p. 334.

quence of limestone alternating with green shale. In the middle and upper part of the formation there is much chert in nodules in the sandstone and in beds, and there are massive beds of dolomite, one of them 30 feet thick. Much of the sandstone is dolomitic and is channeled by solution. The thickest measured section is on Bull Lake Creek where the Tensleep is 535 feet thick. Toward the south the formation thins to 398 feet on Middle Fork of Popo Agie River. Fossils are found in restricted layers, especially in the chert and in the dolomitic beds. Tracks of amphibians have been found in the ripple-marked, cross-bedded sandstone of the upper part of the formation. The invertebrate fauna consists of brachiopods, gastropods, ostracods, foraminifers (including *Fusulina* and *Staffella*), conodonts, and other types. It is distinctly a Des Moines fauna, and present information about the faunas indicates that it is higher than Cherokee. Since no fossils have been found in the lower part it may be that Cherokee time is represented. The Tensleep formation as here defined includes the upper part of the Amsden formation of Darton and that name is dropped.[17]

PERMIAN

Phosphoria formation.—The Phosphoria formation is a thin, lithologically complicated series which rests disconformably on the Tensleep formation. On the north side of Bull Lake Creek a low hill of Tensleep sandstone was covered over by Phosphoria beds, which there consist of sandstone detritus from the Tensleep. The lower Phosphoria consists, above the detrital beds, of chert, sandstone, and rock phosphate. The rock phosphate is an elasmobranch-bearing coquina of *Orbiculoidea* and a dark concretionary phosphate. The middle Phosphoria is limestone, in places siliceous; a thin bed of fossiliferous nodular rock phosphate overlies the limestone and is succeeded at the top of the middle Phosphoria by dark phosphatic shale. The upper part of the Phosphoria is nodular dense chert in a greenish shaly limestone matrix with thin bands of rock phosphate and a bed of green shale at the top overlain by glauconitic limestone and gray massive dolomitic limestone. The thickness of the formation is 300–400 feet. The elasmobranchs of the lower phosphate bed have Pennsylvanian affinities while those of the middle Phosphoria phosphate are closely related to the elasmobranchs of the lower Permian of East Greenland. The faunas of the lower and middle parts of the formation contain many Pennsylvanian relicts, but those of the upper part are distinctively Permian. An undescribed conodont fauna has been col-

[17] C. C. Branson, "Pennsylvanian Formations of Central Wyoming," *Bull. Geol. Soc. America*, Vol. 50 (1939), pp. 1199–1226.

lected from the lower and middle phosphates and consists of *Gondolella Hindeodella*, and another genus. No conodonts are known elsewhere above the lowest part of the Permian except a *Gondolella* species said to be from the Muschelkalk of Germany, but which probably came from the lithologically similar Zechstein. Foraminifera have been found in the middle Phosphoria and have been studied but not described in print. These compare with the upper Pennsylvanian or lower Permian fauna described by Cushman and Waters[18] from a well in Sutton County, Texas, and with the fauna described by Paalzow[19] and by Brand[20] from the Zechstein of Thuringia and Wetterau.

The Phosphoria formation is here considered to be of lower, but not lowest, Permian age because: (1) fourteen of its invertebrate species have also been found in the Pennsylvanian of other regions; (2) the elasmobranch fauna of the middle phosphate closely resembles that of the lower Permian of East Greenland; (3) excepting *Aulosteges hispidus*, none of the peculiar productids of the middle Permian occurs in the Phosphoria; (4) conodonts occurring in the Phosphoria and elsewhere in North America are unknown above the lower part of the lower Permian; (5) the foraminiferal fauna compares closely with that of beds near the Pennsylvanian-Permian boundary in Texas (lack of knowledge of higher faunas other than that of the Neva limestone makes this point of little value). It is true that more Phosphoria species have been reported from the Word than from any other West-Texas Permian formation, but even more Phosphoria species have been reported from upper Pennsylvanian formations.

The Paleozoic-Mesozoic boundary is not marked in the Wind River Range. The lowest Triassic formation shows no physical unconformity with the Phosphoria although the faunas are quite different. The top member of the Phosphoria is massive dolomitic limestone and it is succeeded in most places by thin-bedded friable siltstone. The contrast between the rates of erosion of the siltstone and dolomitic limestone determines the position of the Phosphoria dip slope of the mountains.

TRIASSIC

CHUGWATER GROUP

The Triassic formations were first called redbeds and later Chugwater. On the northeast flank of the Wind River Mountains the group

[18] J. A. Cushman and J. A. Waters, "Upper Paleozoic Foraminifera from Sutton County, Texas," *Jour. Paleontology*, Vol. 2 (1928), pp. 358–71.

[19] Richard Paalzow, "Die Foraminiferen im Zechstein des östlichen Thüringen," *Jahrbuch Preuss. Geol. Landesanst.*, Vol. 56 (1935), pp. 26–45.

[20] Erich Brand, "Ueber Foraminiferen im Zechstein der Wetterau," *Senckenb. Naturf. Ges.*, Vol. 19 (1937), pp. 375–80.

ranges from about 1,200 feet to 1,700 feet thick. In 1931 the senior writer recognized seven formations in the Chugwater, three of which had been named, and described four of them. The names were printed in University of Missouri notebooks in 1934 and the writers submitted a paper to the Geological Society of America in 1936 in which the formations were described and named but the paper has not been published. In 1939 Love[21] described three of the new "members" and the writers are describing one of those formations left over from the earlier paper. A more complete description will appear in a paper soon to be published.

Although the Chugwater is called the redbeds, there is no identifiable "red" color in the group. According to Ridgway color standards the various beds are aüburn, sanford brown, cinnamon, dark brown, apricot buff, buff salmon pink, pale buff, light pink, purple, flesh, ferruginous, and light gray.[22]

Analyses of samples from Bull Lake Creek, taken every 10 feet, show the largest grains to be 0.17 mm. in diameter; modal grains range from 0.01 to 0.07 mm. in diameter. No shale was found. The formations of the group are in descending order: Gypsum Springs, Wyopo, Popo Agie, Crow Mountain, Alcova dolomite, Red Peak, and Dinwoody.

Dinwoody formation.—The Dinwoody formation has long been considered by the writers to be no more than the basal part of the Chugwater (redbed series) where it is locally yellow-brown instead of red. The boundary between the Dinwoody and higher Chugwater can be drawn only on the basis of change in color and colors cross bedding planes sharply. The fauna of the Dinwoody in the Wind River Range consists almost entirely of practically unidentifiable lamellibranchs and some *Lingulas*. Newell and Kimmel[23] have recently succeeded in finding identifiable fossils in the Dinwoody and they believe the fauna to be Triassic. Walter's list published by Thomas[24] was of provisional identifications and is not usable.

Red Peak formation.—The Red Peak formation consists of 600–1,000 feet of commonly designated "red" siltstone. No fossils have

[21] J. D. Love, "Geology along the Southern Margin of the Absaroka Range, Wyoming," *Geol. Soc. America Spec. Paper 20* (1939).

[22] Raymond Trowbridge, "The Physical Composition of the Chugwater Formation," *Univ. Missouri*, unpublished Master's Thesis (1930), pp. 13–15.

[23] H. D. Newell and Bernhard Kimmel, "Permo-Triassic Boundary in Southeastern Idaho and Western Wyoming," *Program 25th Annual Meeting Amer. Assoc. Petrol. Geol.* (Chicago, 1940), p. 53.

[24] H. D. Thomas, "Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, p. 1669.

been found in the formation. The beds are remarkably uniform in thickness and composition.

Alcova dolomite.—The Alcova dolomite is dense light gray dolomite ranging from 1 foot to 25 feet thick in the Wind River Mountains. It contains no fossils in most places, but a nothosaur (a marine reptile) was found in it near Casper.[25] Darton[26] reported fossils from near Thermopolis but they came from a limestone member near the top of the Chugwater. The fossils reported by Lee[27] probably came from one of the upper limestones.

Crow Mountain formation.—The Crow Mountain formation consists of reddish siltstone and is so similar to the Red Peak that it is difficult to distinguish unless the intervening Alcova is located. A 6-inch basal bed made up of fresh fragments of feldspar, mica, and quartz has been recognized on Bull Lake Creek. The materials must have originated from fragmentation by explosion of a granitic rock. As the coarsest fragments are more than two millimeters in diameter the source must have been near. The thickness of the formation is 60–300 feet along the Wind River Range. The Crow Mountain is nonfossiliferous. The contact with the Popo Agie is difficult to distinguish even in those few places where it is exposed although the formations themselves are strikingly unlike.

Popo Agie formation (pronounced po-pozh′-ah).—The Popo Agie formation is the only non-marine part of the Chugwater formation that has been recognized in the Wind River Mountains. It consists of oölitic claystone, bone conglomerate, conglomerate, and siltstone. Good fossils are scarce, but in the course of time a fair number of amphibians and reptiles have been collected which indicate a high Middle or Upper Triassic age. Locally unionids and plant fragments are abundant, but are of little use for age determination. The contrast in lithology and bedding between the Popo Agie formation and the formations above and below should be sufficient to show that this known non-marine member is not of the same origin as the marine beds above and below. The Popo Agie is lenticular and ranges from a few feet to 125 feet in thickness in the Wind River Mountains. It is recognizable on the eastern flank from Dubois to near the south end of the range, but is not known to be present on the western flank. It is

[25] E. C. Case, "A Nothosaur from the Triassic of Wyoming," *Contrib. Mus. Paleon. Univ. Michigan*, Vol. 5 (1936).

[26] N. H. Darton, "Geology of the Owl Creek Mountains," *59th Congress, 1st Sess., Senate Doc. 219* (1906), p. 19.

[27] W. T. Lee, "Correlation of Geologic Formations," *U. S. Geol. Survey Prof. Paper 149* (1927), p. 14.

known elsewhere only on the southern flank of the Owl Creek Range near Bargee, and near Black Mountain, and near Red Creek on the north flank. Although the member is lithologically and faunally totally unlike the rest of the formation it has been mistakenly identified by some workers and the Crow Mountain lumped with it. The Popo Agie member[28] is not the Jelm formation of Knight, which lies near the top of the Chugwater and is 200 miles away. The statement that the faunas are the same is based on the mere fact that some bone scraps were found in the Jelm, none of them identifiable even as to genus.

Wyopo formation (*new name*).—In the Wind River Mountains the Popo Agie beds are overlain by a cliff-forming series of white, buff, light gray, and pink siltstone which is cross-bedded in large part. In the southern part of the range the lower part changes in short distances from light gray to light red. This member is lacking on the southern flank of the Owl Creek Mountains and the Gypsum Spring rests upon the Popo Agie beds. The Wyopo is about 200 feet thick in the Lander region and is less than 100 feet thick near Dubois. An organism of undetermined affinities was found in this formation about 3 miles northeast of Lander. Wyopo, a loading spur on the Northwestern Railway 2 miles northeast of Lander, is the type locality.

Gypsum Spring formation.—The upper member of the Chugwater formation consists of red siltstone with several gypsum beds of irregular thickness and distribution and has near its top three thin persistent limestone members. These limestones contain internal molds of lamellibranchs in large numbers. They are laminated and contorted or "crinkly" and they have been mistaken for the Alcova by some observers. The formation ranges from more than 200 to less than 20 feet.

JURASSIC

The Jurassic in the Wind River Mountains region is made up of two strikingly different formations, the lower (Sundance) marine in origin and the upper (Morrison) non-marine. The lower limit of the Jurassic has been placed at several horizons by geologists but those who have spent some time investigating the problem in the Wind River regions have agreed within narrow limits.

Sundance formation.—The Sundance formation lies with great disconformity on the Chugwater. It may rest upon any of the Gypsum Spring limestones, gypsums, or siltstones, and in Casper Mountain

[28] John G. Bartram, "Triassic-Jurassic Red Beds of the Rocky Mountain Region," *Jour. Geol.*, Vol. 38, No. 4 (1930), pp. 335–45.

it lies on the Wyopo within a few feet of the Alcova. The basal layers contain angular fragments of Chugwater, and well worn pieces of older formations. The Sundance consists of limestone, sandstone, and sandy shale in its lower part and of sandstone, sandy shale, and limestone or sandy limestone in its upper part. A pinkish shaly bed is commonly present near the middle. The upper two-thirds of the Sundance is highly fossiliferous, but fossils are only locally abundant in the lower members. The characteristic forms are columnals of *Pentacrinus*, *Belemnites densus*, *Camptonectes bellistriatus*, and *Gryphaea calceola*, but careful collecting yields a fairly large fauna.

Morrison formation.—The Morrison formation consists of variegated clay, silt, and sandstone with beds that pinch out and change in short distances from one material to another. Eolian sand and loess make up part of the formation in some places. As the Sundance sea withdrew the Morrison seems to have formed as floodplain deposits and alluvial fans on the newly exposed surfaces. The unconformity between Morrison and Sundance is commonly not detectable and nowhere shows a great amount of erosion. In the Wind River region the formation is 350–400 feet thick. Polished pebbles, some of which are probably gastroliths, are abundant in some members, but few dinosaur bones have been collected. One "gastrolith" collected contains a fusulinid similar to a species which occurs in the Tensleep. No adjacent area is known where such material could have been eroded out by Jurassic time. The formation offers little resistance to erosion and with the succeeding Cloverly forms clay slopes opposite the Dakota dip slopes.

CRETACEOUS

The Cretaceous sediments on the east flank of the Wind River Mountains are thicker than those of all other periods combined and their source is an unsolved problem. Neither the stratigraphy nor the paleontology of the Cretaceous in the region has been extensively investigated and the correlations are seriously in doubt. The writers have little to add to the information that has been published and the following discussion is a mere summary. The Cretaceous formations that have been recognized are listed in Table I and although the writers prefer the use of certain names they are in doubt about the best usage.

Dakota group.—The Morrison is overlain unconformably by dark gray shales interbedded with some sandstones; total thickness about 300 feet. The shales are capped by nearly 100 feet of coarse to fine, gray to brown cross-bedded sandstone, the typical Dakota. The shales

have been identified as the Cloverly. The upper sandstone beds of the Cloverly bear many species of plants and sharks but no species of either has been identified. The Dakota sandstone supports prominent hogbacks parallel to the foothills. Many species of plants have been collected from it by N. H. Brown of Lander, Wyoming.

Mowry shale.—In the writers' examination of hundreds of Cretaceous sections on the east flank of the Wind River Mountains they have not been able to distinguish the Thermopolis and on that account they classify the 800 feet of shale between the Dakota and Frontier as Mowry. It consists of dark platy shale with the bedding planes dotted with numerous fish scales. Many of the layers are hard and fissile and many Mowry slopes are covered with fissile shale fragments. Beds of bentonite are present in every section of the shale. Heathman[29] identified 55 beds of bentonite in a section 190 feet thick southeast of Lander with a total of 24.5 feet of bentonite. Dark bluish gray is the predominating color of the formation.

Frontier formation.—The Frontier formation is made up of alternating members of sandstone and shale. In some places a coal bed is present near the middle of the section. Most of the shale and sandstone is gray to light tan in color. The best section known to the writers was measured and described by John Ware,[30] under the direction of the senior writer, at a locality near the highway from Lander to Rawlins, about 25 miles southeast of Lander. Some of the sandstone members yield numerous oysters and other lamellibranchs, gastropods, and rare cephalopods. Some lime nodules in the shales are crowded with fossils.

Cody shale.—About 4,500 feet of dark gray shales interbedded with thin sandstone members succeed the Frontier formation. The name Cody is preferred to Steele as that formation was described as resting on the Frontier in the Bighorn Basin whereas the Steele was described as resting on Niobrara. Near the Wind River Mountains there is no lower division that should be differentiated as the Niobrara formation although fossils of Niobrara age are present.

Mesaverde formation.—The highest Cretaceous formation in the Wind River region is the Mesaverde which consists of about 900 feet of gray to light brown alternating sandstones and shales. Some coal beds are present and as marine fossils have been found in several members the formation must consist of alternating marine and non-

[29] J. H. Heathman, "Bentonite in Wyoming," *Geol. Survey Wyoming Bull. 28* (1939), p. 14.

[30] John Ware, "The Paleontology and Stratigraphy of the Frontier Formation on the East Side of the Wind River Mountains, Wyoming," unpublished thesis, University of Missouri (1927).

marine members. As no outcrops of the Mesaverde are nearer than 10 miles from the foothills of the Wind River Mountains it should not be classed as one of the Wind River formations. Higher Cretaceous formations are not exposed in the immediate vicinity of the range.

After the deposition of the Cretaceous the mountain uplift took place and initiated erosion of all the higher region.

TERTIARY

By early Tertiary time the Wind River Mountains had been deeply eroded. The dipping rocks formed series of hogbacks not greatly different from those that may be seen at present where the Tertiary formations have been stripped off. The Wind River Basin lay between the Owl Creek and Wind River Mountains which had formed during late Cretaceous. The lowest part of the base on which the lowest Tertiary (the Wasatch or Wind River) was deposited now lies about 4,000 feet above sea-level and the highest Wasatch or Wind River on the margins of the Wind River Basin is a little above 7,200 feet.

Most of the material eroded from the Wind River Mountains in late Cretaceous and early Tertiary was carried out of the basin or lies buried in the lowest part where it is not observable excepting where it has been warped upward. The Mesozoic formations had been cut down thousands of feet from the mountain summits in pre-Eocene time and the mountainward margin of the Triassic is now about 7,000 feet above sea-level where the Eocene rests on it.

EOCENE

In the Wind River Basin the best Eocene section is along Beaver Divide where Granger[31] identified Wasatch, Bridger, and Uinta. Later writers have used Wind River for Wasatch.

Wind River formation.—The writers are using the name Wind River but believe that much more investigation, both stratigraphic and paleontologic, must be undertaken before satisfactory conclusions can be reached. The oldest Wind River deposits in the basin are not exposed. The formation is composed of alluvial deposits made up of sand, silt, clay, and pebbles, poorly sorted and poorly bedded. In places granite pebbles and cobbles are in the formation indicating that pre-Cambrian granites were exposed in the mountains when the Wind River formation was forming. Part of the formation is red to gray in color and yellow and green are common colors. Most of the significant

[31] Walter Granger, "Tertiary Faunal Horizons in the Wind River Basin, Wyoming, with Descriptions of New Eocene Mammals," *Bull. Amer. Mus. Nat. Hist.*, Vol. 28 (1910).

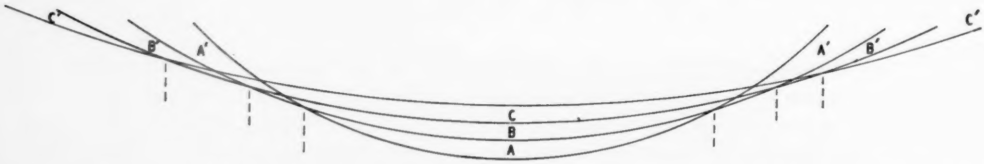

FIG. 3.—Cross-sectional diagram of an intermontane basin. Successive layers of sediment are deposited farther back and higher on basin walls. Earliest series (*A*) is derived from erosion in triangle *A′* and is deposited between inner pair of vertical dashed lines. Series *B* is eroded from triangle *B′* and is deposited between middle pair of dashed lines; series *C* is eroded from triangle *C′* and overlaps basin walls to outer pair of dashed lines. Section taken in middle of basin includes series *A–C*, but one taken just within outer dashed line has only youngest series. Diagram shows theoretical levels of erosion at different stages under uniform conditions.

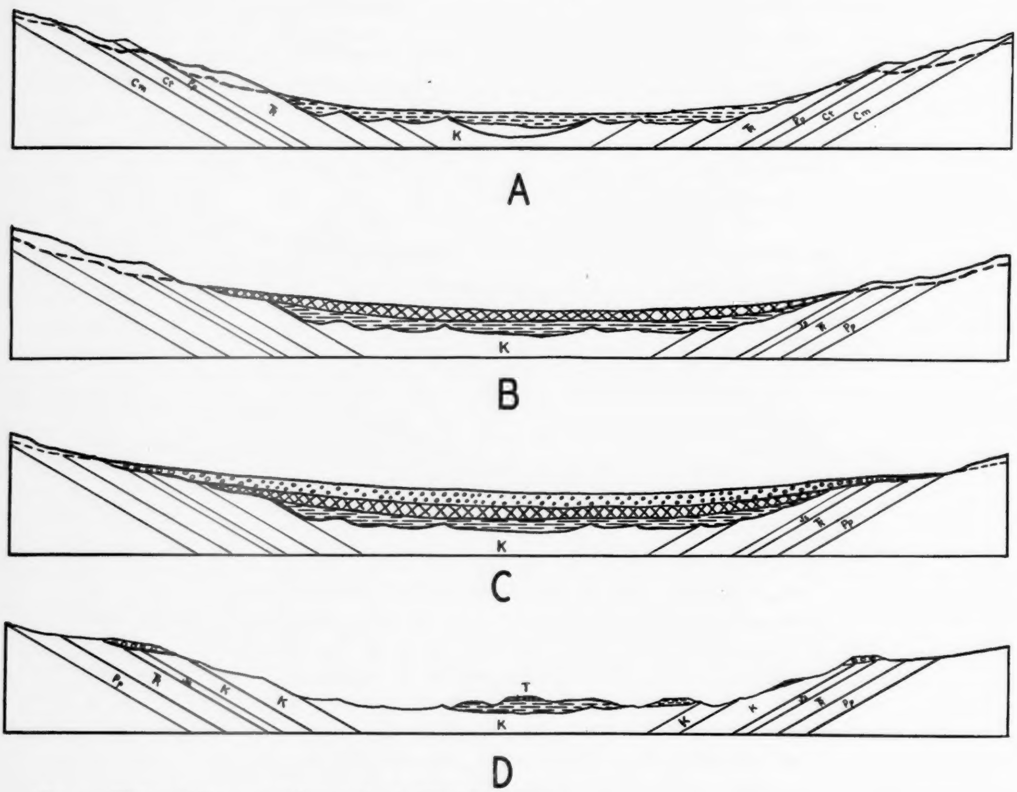

FIG. 4.—History of Cenozoic sedimentation in Wind River Basin.

A. Eocene formations deposited over Mesozoic hogbacks (dashed line shows erosional level attained during sedimentation).

B. Oligocene deposition extending onto lower part of erosional surface developed during Eocene.

C. Pliocene? deposition of Burnt Gulch conglomerate overlapping Phosphoria and in places earlier formations.

D. Present conditions in basin; Burnt Gulch conglomerate in remnants on Triassic and late Paleozoic hills; Eocene in center of basin; Oligocene in higher buttes and hills remote from range.

fossils are of mammals and identifiable specimens are rare. Sinclair and Granger believe that the known fossils indicate upper Wasatch age. The lower part of the formation has furnished no significant fossils, but it probably is equivalent to lower Wasatch. Fossil plants from the formation promise results with extensive study. Bauer says that the exposed thickness of the formation in the southwestern part of the Wind River Basin (a few miles east of the southern end of the Wind River Mountains) is 1,200 feet and that a thickness of 4,000 feet is probable in the northern end of the basin.

Bridger formation.—The Bridger formation has been identified by its mammalian fossils on Beaver Divide about 10 miles east of the south end of the range where its greatest thickness is about 400 feet according to Sinclair and Granger.[32] It seems to pinch out westward a short distance east of the mountains. The formation lacks the red colors of the Wind River but is made up of similar sediments, with poor bedding and much interfingering of beds. Volcanic ash (white lignitic tuff of Sinclair and Granger) is present in some places.

Uinta formation.—The Uinta formation has been identified in Beaver Divide on the basis of a few mammalian fossils. Its materials are better sorted and finer than those of the Bridger although the writers would not identify them as lake deposits.[33] The colors of the sediments are in the main gray and green with buff and brown variations. The lenticular beds of alluvial deposits make identification of unconformities difficult and the relationship of the Uinta to the Bridger is uncertain. The maximum thickness of the Uinta in Beaver Divide is about 300 feet according to Sinclair and Granger.[34]

Wasatch formation.—Although Wasatch time is represented by thick sediments east of the Wind River Mountains all of which are called Wind River in this paper, it is only south and west of the mountains that Wasatch formations are positively identified. There it consists largely of drab clay banded with pink and maroon colors. Thin beds of gray, yellow, and brown sandstone and conglomerates made of small pebbles are interbedded. Bradley[35] and Nace[36] have described the Wasatch and Green River in the region south of the mountains. The alluvial deposits are similar to those along Beaver

[32] W. J. Sinclair and Walter Granger, "Eocene and Oligocene of the Wind River and Bighorn Basins," *Bull. Amer. Mus. Nat. Hist.*, Vol. 30 (1911), p. 94.

[33] C. Max Bauer, *op. cit.*, p. 678.

[34] W. J. Sinclair and Walter Granger, *op. cit.*, p. 89.

[35] W. H. Bradley, "Shore Phases of the Green River Formation in Northern Sweetwater County, Wyoming," *U. S. Geol. Survey Prof. Paper 140 D* (1925).

[36] Raymond L. Nace, "Geology of the Northwest Part of the Red Desert, Sweetwater and Fremont Counties, Wyoming," *Geol. Survey Wyoming Bull. 27* (1939).

Divide but are finer-grained. Channel deposits within the better bedded floodplain deposits are common. The south end of the range which furnished the sediments south of the mountains was lower than the mountains farther north from which the Wind River Basin sediments came.

Green River formation.—The north edge of the Green River formation lies near the range on the south and west. The lake in which the sediments were deposited was separated from the Wind River Basin by the so-called "Granite Mountains" which parallel Beaver Divide just south of it. The Green River interfingers with the Wasatch near the Wind River Range, the Wasatch being the alluvial deposits near the source of sediments and the Green River the lake deposits. The Green River forms no part of the Wind River Mountains.

OLIGOCENE

Preceding the Oligocene some uplift of the central part of the range took place and the igneous and metamorphic rocks furnished materials as coarse as boulders for a conglomerate of which there are remnants 15 miles east of the range on Beaver Divide and 12 miles south on Oregon Buttes. Following the formation of the conglomerate volcanic ash deposits must have been widespread around the south end of the range and in some places, particularly on Beaver Divide, more than 500 feet of tuff has survived erosion. None of the tuff is known within the range.

White River formation.—The conglomerates and tuffs of the Oligocene have been classed as White River by most investigators and Bauer[37] and Nace[38] have considered that Chadron and Brule can be identified. The conglomerate was named Sweetwater by Bauer[39] but the name was preoccupied and Nace[40] has substituted the name Beaver Divide conglomerate.

POST-OLIGOCENE

Alluvial fan remnants, possibly Miocene or Pliocene in age, here named Burnt Gulch formation, are the only post-Oligocene deposits known excepting Pleistocene and recent till and recent alluvium. The basin near the mountains on the east side must have been filled to about the 7,500-foot level and later have been peneplaned with the

[37] C. Max Bauer, *op. cit.*, p. 680.

[38] Raymond L. Nace, *op. cit.*, p. 11.

[39] C. Max Bauer, *op. cit.*, p. 678.

[40] Raymond L. Nace, *op. cit.*, pp. 32–35.

top of the peneplain cut on the alluvial fans.[41] Many remnants of this peneplain are present in the east slope of the mountains, the most accessible being at the south end of Red Canyon, Table Mountain, North Fork of Little Wind River, Bull Lake Creek, and Dinwoody Creek. The writers are naming these deposits the Burnt Gulch conglomerate with type locality at the west end of Table Mountain on Burnt Gulch.

Burnt Gulch conglomerate.—The Burnt Gulch formation is made up in the main of boulders, gravel, and sand, almost without stratification. Boulders more than 20 feet in diameter have been measured, but away from the mountains they decrease in size and few as much as one foot in diameter are more than 15 miles from their source. Near the mountains most of the materials are of granodiorites and schists at the south end of the range and of granodiorites from Table Mountain northward. A thickness of 300 feet has been measured on Dinwoody Creek where the best exposures occur. In most places the conglomerates are poorly cemented but on Dinwoody Creek and North Fork of Little Wind River the cementation is firm enough to allow vertical bluffs more than 150 feet high to form. It is probable that the boulders that are widely scattered over the Wind River Basin have been let down from the Burnt Gulch conglomerate.

PLEISTOCENE AND RECENT

Glaciation.—Mountain glaciers formed in the Wind River Mountains during late Pleistocene and moved from the peaks through the canyons, and in the northern part of the range extended out into the margin of the Wind River Basin. On Dinwoody Creek and Bull Lake Creek the respective terminal moraines lie on the higher beds of the Cretaceous and the moraines are about 2 miles wide from front to back. On South Fork of Little Wind River the terminal moraine is just in front of the Phosphoria dip slope, as it is on the North Fork of Popo Agie River. On Middle Fork of Popo Agie River the ice tongue did not reach into the last $\frac{1}{4}$ mile of the canyon and accordingly the mouth of the canyon is narrow while the upper part is distinctly U-shaped. Outwash deposits form ridges on the sides of the valley outside the mouth of the canyon and the valley train of boulders is clearly identifiable for some distance down the valley. On Little Popo Agie River the glacier did not reach the Paleozoic formations. Along all of the glaciated valleys there are numerous small recessional moraines which show that the edges of the glaciers halted many times during retreat.

[41] Lewis G. Westgate and E. B. Branson, "The Later Cenozoic History of the Wind River Mountains, Wyoming," *Jour. Geol.*, Vol. 21 (1913), pp. 142–159.

All of the material in the glacial deposits is perfectly fresh and there is no evidence on the east side of the range of more than one advance of the ice. In many places weathered Burnt Gulch boulders are associated with glacial boulders and have been identified as weathered glacial boulders. There is some possibility that the deposits along Green River in the northwestern part of the range may represent two stages. A reported pre-Pleistocene glacial deposit about eight miles south of the Bonneville Range, examined by the writers, proved to be a granite ridge buried by Eocene sediments.

On the west side of the Wind River Range moraines are much larger than on the east, in some places extending for more than ten miles from the outermost part of the end moraine to the innermost. These moraines cover the pre-Cambrian-Eocene contact in most places.

Several small glaciers are present in the heart of the range and serve to connect Pleistocene glaciation with Recent.

Physiography

The Wind River Range was folded during the Laramide revolution and the folding was completed before Wasatch time except for minor uplifts and folding of small areas. The Wind River-Wasatch sediments lie horizontally against and over hogbacks and valleys developed on Mesozoic and even Paleozoic beds before the lower Eocene. Along the front of the range the Mesozoic hogbacks have been re-exposed by post-Oligocene erosion. The upper member of the Phosphoria formation is much more resistant to erosion than the overlying Chugwater and as a result of erosive work early and late in the Cenozoic this member supports a long, well developed dip slope. The dip slope is the prominent feature of the foothills. It ranges from $\frac{1}{2}$ mile to 2 miles long. The summits of the dip slopes between canyons are concordant with the Table Mountain level and some of the dip-slope summits are capped by Burnt Gulch conglomerate. The upper end of the dip slope consists of a knoll of chert, which formed from the weathering of the nodular cherts in the lower part of the upper Phosphoria. The saddle behind this knoll exposes the phosphate bed of the middle Phosphoria. The fossiliferous limestone of the middle Phosphoria makes a short dip slope behind the saddle and a long dip slope is supported by the siliceous beds of the lower Phosphoria below the lower phosphate bed. The sandstone beds of the upper part of the Tensleep formation form an irregular dip slope, and the Madison limestone a poorly developed one. The top of the Bighorn dolomite is a dip slope which terminates in prominent cliffs, directed toward the center of the range, which

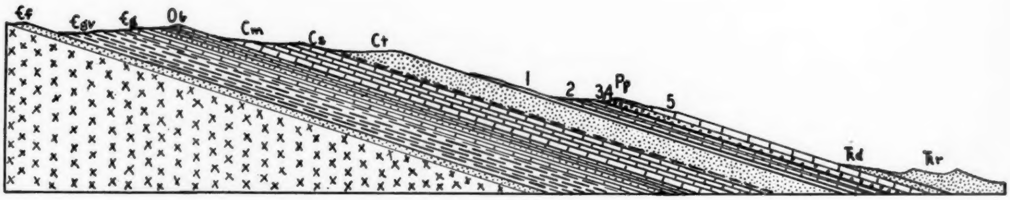

FIG. 5.—Profile of foothills on eastern side of Wind River Mountains to show relationship of dip slope to bed rock.

TRr: Red Peak formation
TRd: Dinwoody formation; Overlaps base of dip slope
Pp: Phosphoria formation

5: Dolomitic limestone; forms face of dip slope
4: Nodular chert; knoll at top of dip slope
3: Rock phosphate; exposed in saddle
2: Fossiliferous limestone; weakly developed dip slope
1: Chert and siliceous limestone; secondary dip slope

Ct: Tensleep formation; supports irregular dip slope
Cs: Sacajawea formation; exposed in few places
Cm: Madison limestone; limestone cliffs
Ob: Bighorn dolomite; prominent bluff
Cg: Gallatin formation; ledges in places
Cgv: Gros Ventre shale; grassed clay slope
Cf: Flathead sandstone; forested slabby slope

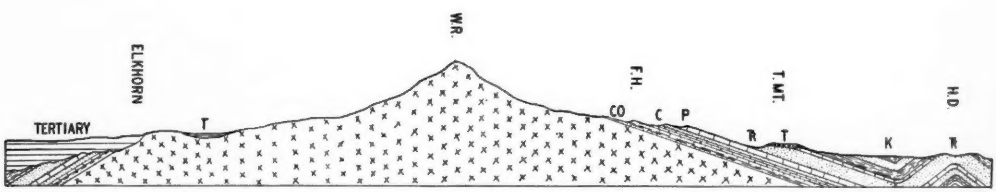

FIG. 6.—Cross section of Wind River Mountains from Hudson Dome to Elkhorn to show postulated relationships of Tertiary sediments to older rocks on west side.

overlook the grassy meadows on the Gros Ventre shale. The Flathead sandstone supports a forested slope covered by slabs of Flathead sandstone.

TABLE II

OUTLINE OF GEOLOGIC HISTORY IN WIND RIVER MOUNTAINS

Recent	Erosion, terracing, formation of alluvial fans and floodplain deposits
Pleistocene	Advance and retreat of mountain glaciers, stream erosion, and deposition
Pliocene?	Filling of Wind River Basin to Burnt Gulch level and piracy of Wind River by Bighorn River, creation of Table Mountain plain, erosion on west side of range
Post-Oligocene	Erosion to Beaver Divide level
Oligocene	White River stream deposits and volcanics
Eocene	Fluviatile deposition in Wind River Basin and on north and west sides of mountains, Green River lake on south and west
Late Cretaceous and Early Eocene	Erosion to high-level peneplain, followed by uplift and erosion to topography similar to that of present
Upper Cretaceous	Folding, overthrusting, faulting of range, widespread flooding, marine and non-marine deposition, withdrawal
Lower Cretaceous	Non-marine deposits and marine deposition, withdrawal
Jurassic	Invasion by Sundance sea, withdrawal of Sundance sea, followed by non-marine Morrison deposition
Triassic	Marine invasion with some non-marine deposition, chemical deposits in relict seas
Permian	Marine invasion and withdrawal
Pennsylvanian	Marine invasion and withdrawal
Mississippian	Marine invasion, withdrawal, second marine invasion, second withdrawal
Devonian	Middle? Devonian marine invasion, Upper? Devonian withdrawal of seas
Silurian	Erosion
Upper Ordovician	Marine invasion and withdrawal of seas
Middle-Upper Cambrian	Marine invasion and withdrawal of seas
Pre-Cambrian	Sedimentation, metamorphism, intrusion of granite batholiths

The central part of the range consists of glaciated peaks, of exfoliated granite knobs and adjacent alluvial fans of granite detritus, and along the major stream courses of glacial and glacio-fluviatile deposits. A high-level erosional surface at 12,000 feet is well developed in the northern part of the range and has been interpreted as a Pliocene? surface.[42] It seems more likely to the writers that the surface is pre-Wasatch.

According to Westgate and Branson[43] a lower plain was developed on the schists at the south end of the range at an elevation of about 9,000 feet. A second plain is represented by the high flats between Sweetwater River and Beaver Divide and by the plains of the southern end of the Wind River Range. This plain is developed upon the

[42] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *Jour. Geol.*, Vol. 23 (1915), pp. 97–117, 193–217.

[43] L. G. Westgate and E. B. Branson, *op. cit.*, pp. 147–48.

Oligocene sediments and also truncates hills of Paleozoic and pre-Cambrian rocks. The surface is at an elevation of 8,000–8,500 feet.

A third plain is developed on the Burnt Gulch conglomerate, the top of Table Mountain being a remnant, at 7,200 feet. Wind River Basin was filled by Burnt Gulch sediments and Wind River had cut approximately 200 feet below the level of Table Mountain before it was pirated across the Owl Creek Mountains by a tributary of Bighorn River and ceased to drain into the Sweetwater. The abandoned valley through which Wind River flowed into the Sweetwater is now a broad notch in Beaver Divide about 6 miles east of Hailey.

Erosion since Burnt Gulch time has removed or let down nearly all of the Burnt Gulch deposits and near the range has commonly cut down to or below the pre-Eocene level. The center of the Wind River Basin is now covered by Eocene sediments and the entire Eocene-Oligocene sequence is preserved on Beaver Divide and in the northern end of the basin.

Structure

The Wind River Range is basically an asymmetrical anticline with axis trending N. 36° W. Neither Paleozoic nor Mesozoic rocks are exposed on the west side of the range excepting at the northern part and in a small area southeast of Pinedale where rocks of Pennsylvanian and possibly Mississippian age are exposed. A large normal fault has been postulated by authors to account for this fact, but the writers do not subscribe to this theory. They believe that Paleozoic and Mesozoic hogbacks exist on the west side of the range, but that they are relatively low and are overlapped by Cenozoic deposits (Fig. 6) which extend onto the granite. There is no physiographic evidence of faulting in the region of the postulated fault. The spurs between valleys are not of the same westward extent; the granite slopes are gentle, not steep, indeed the road from Elkhorn to Dutch Joe Ranger Station and Big Sandy Opening passes easily from Tertiary onto the granite and by easy grades deep into the granite hills. The altitude of the granite-Tertiary contact is 7,200 feet, which corresponds with the elevation of Table Mountain and of the top of the dip slopes on the east side of the range. Near Big Piney Post Office knobs of granite may be seen well outside the postulated fault line. Further, Paleozoic and Mesozoic sediments are present in the region of Green River Lakes on the west side of the northern part of the range. Their relationship to the possible structural line farther south is indeterminate because they lie in a structurally complicated manner which permits trends to be followed for short distances only. However, no fault of the magnitude of the

postulated one is present in the Green River Lakes area. A recently completed boring near Pinedale was reported to have bottomed in Tertiary at 10,000 feet.[44] This indicates faulting in that area, as the pre-Tertiary surface is more than 3,000 feet below sea-level.

Faulting on a large scale is responsible for the offset position of Sheep Mountain, near Hailey, east of the south end of the range. Sheep Mountain is a faulted dome which has been offset toward the east. Small thrusts in the flanks of the main structure may be seen on the west side of Sheep Mountain.

Overthrusting on a small scale brings the Gallatin over the Madison on a small spur east of Fossil Hill along the south side of Middle Fork of Popo Agie River. The fault trace can be followed southward several miles.

The granites of the west side of the range have been extensively faulted and streams and lakes are aligned according to structure (Fig. 7). Big Sandy Lake lies at the intersection of three sets of these faults, and Little Sandy Lake is at another such intersection. The west shore of Clear Lake and the east shores of Marms Lake and Lake Elizabeth are certainly fault scarps since they are straight lines. The flanks of the granite peaks bounding the valleys are fault-line scarps, seen upon examination to be long straight steep slopes paralleling the fault valleys. These fault lines can be traced for nearly 100 miles northward and over to the eastern slope of the range. They are unmistakable in airplane photographs and it is from these that the writers got their first hint of their presence (Fig. 7).

Parallel with the axis of the range and 7 miles east of the base of the dip slope on the top of the Paleozoic rocks is a line of anticlines parallel with the axis of the Wind River anticline. This chain of anticlines is made up of Hudson Dome, Dallas Dome, Derby Dome, and Sage Creek anticline. Each is eroded into the Chugwater and each produces black oil. Both dip and strike faults are common on these domes. Near the southern end of the range there is a small, highly asymmetrical anticline along Red Creek near Little Popo Agie River. The eastern face of this anticline is supported by the dip slope-forming Phosphoria lying at a 15° angle, which is only slightly steeper than the normal dip slope. The west limb of the anticline dips at an angle of about 75° and the lower part of the Chugwater is folded in against the foot of the range at the base of the normal dip slope (Fig. 8).

At the southeast the older rocks constituting the Wind River Mountains are overlapped by Tertiary sediments of the Beaver Divide

[44] C. E. Dobbin, "Developments in Rocky Mountain Region in 1939," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 1110.

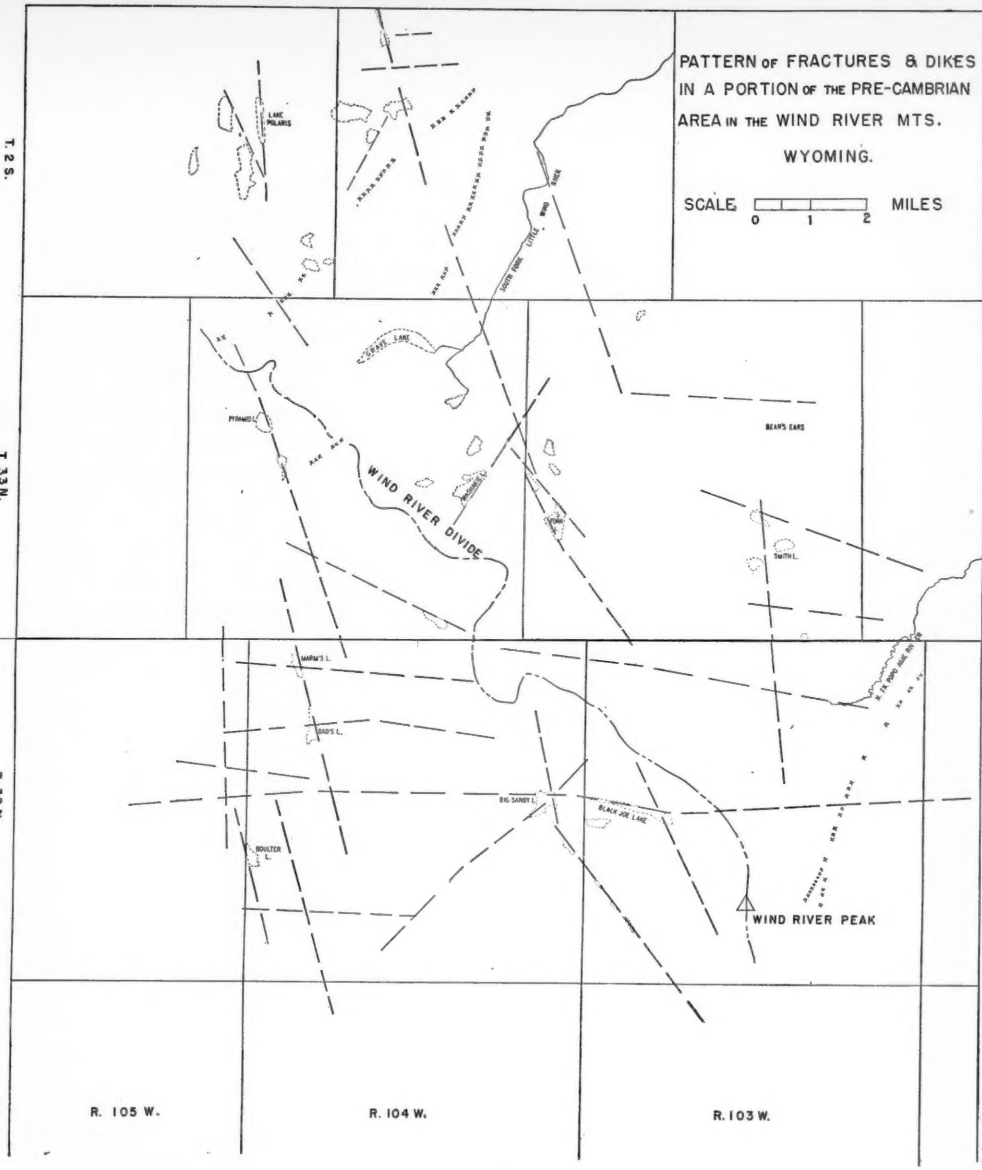

FIG. 7

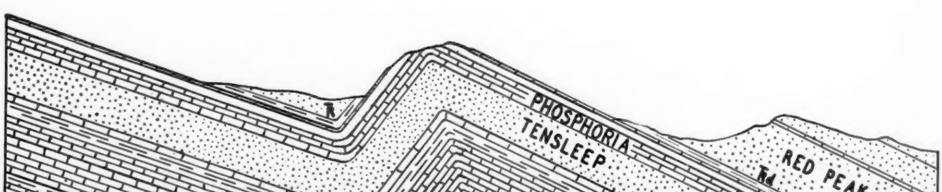

FIG. 8.—Cross section of hidden anticline on Red Canyon southeast of mouth of Little Popo Agie River Canyon.

area. These lie over the Mesozoic hogbacks and overlap even upon the granite as on the switch-backs on the Lander-Atlantic City road at the head of Twin Creek and near Elkhorn and Boulder. In places the older rocks may be seen projecting through the Tertiary, schists near Sweetwater River along the road to Muddy Gap, granite and Flathead about 5 miles west of this point, Madison about 10 miles south of Sandraw, granite near Boulder. Eastward along the steep face of the Beaver Divide plain an outlying anticline is partly exposed where it projects from beneath the Tertiary. This is the Warm Springs anticline of Hares.[45] The anticline is asymmetrical toward the north and Madison limestone is exposed near its apex where it becomes covered by the Tertiary sediments of Beaver Divide.

It seems likely that northwest-southeast-trending anticlines are present beneath the Tertiary cover of Wind River Basin. All structures adjacent to the basin have that trend and some are overlapped by Tertiary. There is no reason to suppose that the structural pattern is not maintained in the rocks of the basin floor.

Petroleum Possibilities

The oldest potential reservoir of interest is the Lander sandstone of Ordovician age. In the Wind River Mountains this formation is quartzitic and lenticular and there is no chance of petroleum in it. In the Bighorn Mountains it is permeable and would make a good reservoir rock, but there is no surface indication of carbon content.

The Madison contains small masses of saturated limestone and offers some prospect of thick saturated members in deeply covered places. There are no good sands and no favorable limestones in the Sacajawea. The Tensleep formation is the best Paleozoic reservoir. The upper part and much of the middle part consist of cross-bedded sandstones many of which would make fine reservoir beds, but some of the sandstones are dolomitic and impervious. All of the Tensleep sands are fine-grained and well sorted. The thick sandstone bed at the base of the formation is not widely distributed. A black, heavy petroleum has been produced from Tensleep sands in the Dallas, Derby, and Hudson fields in the foothills of the Wind River Mountains.

Although the Phosphoria formation has no good reservoir beds, it has produced from the same wells for more than 40 years in the Dallas field. A thick chert member near the base is saturated with petroleum where it is exposed on Bull Lake Creek and geodes in the lower part of the formation contain hydrocarbons. The dark carbonaceous phosphatic shale of the middle part is a possible source rock.

[45] C. J. Hares, "Anticlines in Central Wyoming," *U. S. Geol. Survey Bull. 641* (1916), pp. 233–79.

The Dinwoody sands have yielded black oil and a small amount has been recovered from sands higher in the Chugwater. Sundance sands are becoming important producers in other parts of Wyoming, but have not been tested in the Wind River region.

The Dakota sandstone is a fine reservoir of light oil in some parts of Wyoming, but no structure favorable to recovery from this formation has been tested in the Wind River area. The Sand Draw gas field may derive some of its gas from the Dakota. The Mowry shale is the source of shale oil which was produced from extremely shallow wells near Lander (the old Plunkett field), but there has been no production for many years.

The Frontier sands are potential reservoirs of Cretaceous oil and gas and small production comes from these members in Sandraw field. Elsewhere in Wyoming these sands are important producers.

Production in the Pilot Butte field, 30 miles northwest of Lander, comes from the shales of the Cody.

As no large area of Tertiary of other than fluviatile origin is present near the mountains there is little possibility of Tertiary oil production. The Green River lake deposits are near the mountains on the west and southwest, but none of the Green River oil shales appears in the mountain region.

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VOL. 25, NO. 1 (JANUARY, 1941), PP. 152-160, 2 FIGS.

NEW SOURCE FOR SODIUM SULPHATE IN NEW MEXICO[1]

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ABSTRACT

The discovery of sodium sulphate-bearing brines west of the Pecos River in southeastern New Mexico within a short distance of the potash mines gives promise for commercial development if sufficient reserves can be located. The brines are found in the Castile formation where weathering has altered the anhydrite. A theory is postulated to explain the origin and accumulation of the brines. A brief summary of sodium sulphate production in the southwestern states is given.

INTRODUCTION

Sodium sulphate is an important chemical in the heavy industries. It is essential to the manufacture of kraft paper, glass and ceramic products, textiles and rayon. Most of the sodium sulphate consumed is the result of direct or by-product chemical production, and may originate within the manufacturing plant consuming it. The customary operation is to treat salt with sulphuric acid but other methods are also utilized depending on the relative cost and abundance of the necessary ingredients.

RECENT DEVELOPMENTS IN NEW MEXICO

In 1906 a well was drilled for water on the Forehand Ranch in Sec. 30, T. 25 S., R. 27 E., Eddy County. At 160 feet a strong brine was encountered which when spread out formed a frosty white crust of salts upon the ground. In 1934 another test for water encountered a similar brine at 170–172 feet on the Pardue Ranch in Sec. 29, T. 24 S., R. 26 E., Eddy County. An analysis of this brine showed an abundance of sodium sulphate.

Within the interval between these two discoveries a potash industry had been established east of Carlsbad, New Mexico (Fig. 1), based on mining and refining the mineral sylvite, the chloride of potassium. It was at once evident that if a sufficient body of sulphate brine could be located some of the potassium chloride might be converted to sulphate by treating it with sodium sulphate to make a potassium sulphate fertilizer.

A somewhat similar conversion of New Mexico potash salts is already in operation in Tulsa, Oklahoma, where sulphuric acid produced in excess of the local market demand is now being employed to

[1] Manuscript received, August 20, 1940. Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] United States Geological Survey.

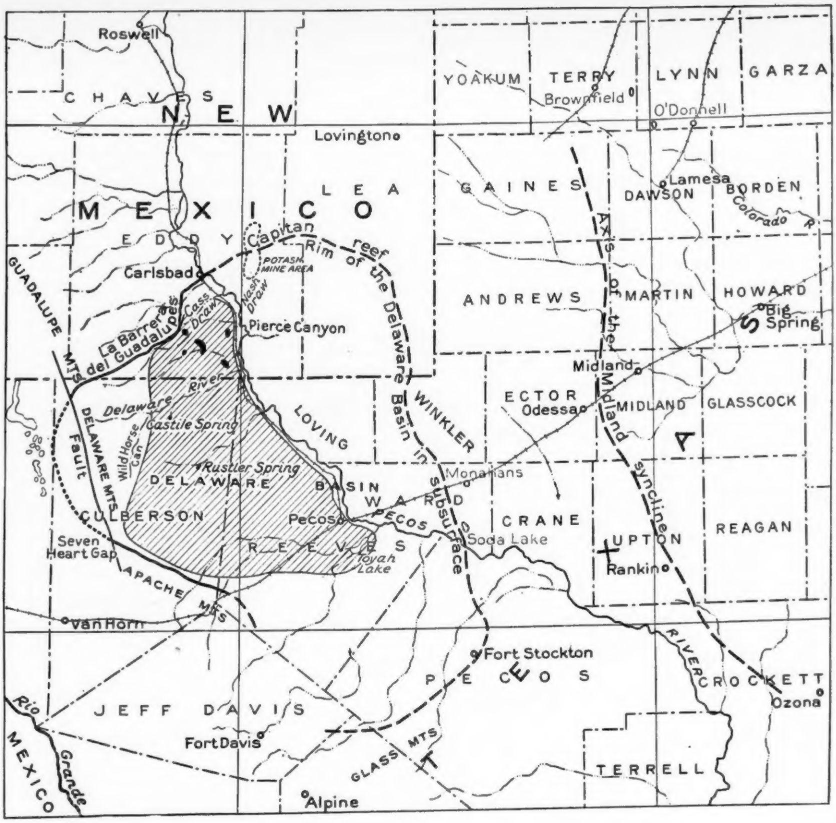

FIG. 1.—Map of part of southeastern New Mexico and western Texas showing places where brines have been located in New Mexico (solid black); area (hachured) within which brines might be found west of Pecos River; and location of sodium sulphate-producing lakes in Ward, Terry, and Lynn counties, Texas.

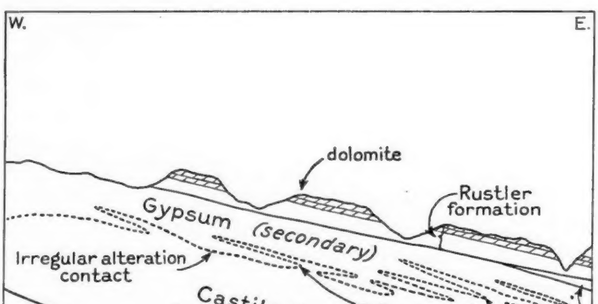

FIG. 2.—Diagrammatic cross section of area west of Pecos River south of Carlsbad, Eddy County, New Mexico, showing postulated character of pockets retaining sodium sulphate-bearing brines.

change the chloride to sulphate, and, what is possibly more important, to obtain thereby hydrochloric acid for which there is a ready sale for acidizing oil wells. Thus a dual benefit results from such a simple chemical exchange.

Interest aroused in the possibilities of sodium sulphate has resulted in the drilling of more than 30 test wells in the last 3 years; 20 of them during 1939. As a result three or more areas are known to have possible economic value though little is yet known about the area underlain by brine in any given place or the quantity of brine present. The results, however, are believed to be sufficiently encouraging to warrant cautious trial development.

CHEMICAL CHARACTER OF BRINE

In Table I are given the chemical analyses of four brines from different localities in the potential sulphate area in Eddy County, New Mexico.

TABLE I

CHEMICAL ANALYSES OF FOUR BRINES, EDDY COUNTY, NEW MEXICO

(Laboratory of the United States Geological Survey, Midwest, Wyoming)

		Grams per Liter			
		1	2	3	4
Magnesium	Mg	41.3	46.2	53.5	39.6
Sodium*	Na	43.1	59.5	61.1	32.3
Potassium	K	16.6	1.8	4.6	1.2
Sulphate	SO_4	236.7	245.5	304.5	187.2
Chloride	Cl	24.8	39.7	24.4	25.4
Carbonate	CO_3	0.3		0.7	
Bicarbonate	HCO_3	1.0	4.5	1.8	1.7
Borate	B_4O_7	2.9	10.3	7.4	4.0
Total solids		366.7	407.5	458.0	291.4
Specific gravity		1.290	1.320	1.363	1.236

1. Forehand well No. 2, Sec. 25, T. 25 S., R. 26 E.
2. Mullen well No. 1, Sec. 30, T. 25 S., R. 26 E.
3. Gates-Pardue-Guitar No. 1, Sec. 26, T. 25 S., R. 26 E.
4. D. P. Welch No. 2, Sec. 8, T. 26 S., R. 27 E.

* Sodium calculated; other constituents determined.

It is worthy of note that all the brines contain the same elements and in somewhat similar proportions. The major components, Mg, Na, and SO_4, vary in total amount in proportion to the density of the brine, though the quantity of the minor constituents does not follow this simple rule. Some calcium and fluorine, not indicated in the analyses, may also be present.

If these four analyses are now recalculated on the basis of the maximum possible sodium sulphate combination and of the normal

succession of combinations of the remaining ions in solutions, the results obtained are shown in Table II.

TABLE II

ANALYSES OF BRINES (TABLE I) RECALCULATED ON BASIS OF MAXIMUM SODIUM SULPHATE

	Grams per Liter			
	1	2	3	4
Na_2SO_4	132.9	183.7	188.6	99.9
$MgSO_4$	158.4	149.1	214.8	148.1
K_2SO_4	37.1	4.1	10.1	2.7
$MgCl_2$	33.4	53.4	32.7	34.1
$MgCO_3$	1.9	6.3	3.4	2.4
MgB_4O_7	3.8	13.3	9.6	5.2
Total solids	367.5	409.9	459.3	292.4
Percentage of Na_2SO_4 in total solids	36	45	41	34

The percentages of Na_2SO_4 in the total solids given in the table are the theoretical maxima recoverable from the brines. How much may actually be recovered will depend on the efficiency of the process employed.

STRATIGRAPHY OF AREA

The brine areas so far discovered lie within the Delaware basin; a roughly circular structural depression more than 100 miles in diameter. The rim of this basin is made of Permian limestones which grade into the sandstones that form the bottom of the basin. Overlying the sandstones in ascending order are the Castile, Salado, and Rustler formations also of the Permian. In a general way, the Castile and Salado are structurally conformable, but the Rustler here lies on a truncated surface of the Salado, which, west of the Pecos River, has been completely removed, so that the Rustler rests directly on the Castile. This is probably because of slight tilting of the basin in Permian time; however, in a later geologic period the region was again uplifted, so the Rustler beds now dip approximately 1 foot in 100 feet east-southeast. Subsequent erosion has removed not only the younger rocks above the Permian but much of the Rustler itself, leaving scattered remnants of the basal part of the formation lying on the Castile. Toward the west, the Castile has in turn been truncated by erosion, so that near Wildhorse Canyon, Texas, the underlying sandstones of the Delaware Mountain formation are exposed. Though this description applies more particularly to that portion of the Delaware basin west of the Pecos River in New Mexico it also holds true for the contiguous area in Texas.

Castile formation.—The Castile formation is composed of 1,000–2,000 feet of banded anhydrite in which the bands are defined by calcite stained with dark organic matter. Some of the basal beds are all calcite rather than anhydrite. East of the Pecos River beds of halite are included.

Salado formation.—The Salado formation ranges from 1,000 to 3,000 feet in thickness and is composed mainly of halite, but with beds of anhydrite, polyhalite, and locally rich deposits of potash salts. Almost none of the upper part of the Salado remains west of the Pecos in New Mexico and very little of the lower part extends more than a few miles west of the river. Though erosion of the Salado began in Permian time, no doubt the surface of the formation has been further modified by subsequent erosion, the amount of which is at present indeterminable.

Rustler formation.—The Rustler formation averages 300–500 feet thick and is made up of anhydrite, siltstones, redbeds, and magnesian limestones. The main magnesian limestone member, 35 feet thick, lies at the top of the lower part of the Rustler and is overlain by anhydrite and some redbeds. Beneath it are gray silts, redbeds, and anhydrite. The resistant character of the magnesian limestone of the Rustler explains its preservation as a capping of the mesas and in the rolling hills that modify an otherwise flattish terraine underlain by the Castile formation.

ALTERATION OF ANHYDRITE

Travelling across this terraine one observes an abundance of gypsum but no anhydrite. That the great body of calcium sulphate in the Delaware basin is anhydrite is proved by cuttings obtained from wells drilled deep into the deposits. The exposed gypsum is a surficial alteration of the underlying anhydrite, a product of weathering. This alteration progresses downward at different rates in different localities. It produces a relatively porous gypsiferous zone overlying a more dense impervious anhydrite mass. The contact is not sharp but is a fairly well defined undulating surface somewhat parallelling the land surface. In New Mexico west of the Pecos it is generally found at a depth of about 200 feet and as this surface conforms more with the topographic than the stratigraphic control it cuts the bedding at a low angle. Hence ground water percolating downward through the inclined beds would tend to travel along this irregular surface and in the irregularly altered zone just above it.

Though the regional dip of the Rustler is about 50 feet to the mile southeastward, that of the underlying Castile is slightly more. The porous gypsiferous zone above the massive anhydrite apparently

provides traps, which form inverted closures or pockets where fluids may find geologically brief lodgment (Fig. 2).

The action of a normal ground-water circulation is to remove from the rocks the substances which it has taken into solution. In a region of limited rainfall, perched ground-water circulation, and abundant soluble salts, water quickly accumulates salts. As the water in transit across the vadose zone in the porous gypsum trickles downward from one temporary perched pocket to another to the basal ground-water table at or near the alteration contact, the water becomes dense with accumulated salts. These dense, high-gravity brines are retained in the basal traps only so long as no lower outlet of the trap is found. Waters of less density than those already in the trap cannot displace them but must override them. If, however, a lower outlet develops by pressure or weathering on the downdip side of the trap the accumulated brine is released to enter the realm of free ground-water circulation and to pass eventually to the surface drainage system.

FORMATION OF BRINE

Meteoric waters in becoming a part of the ground-water system west of the Pecos River can acquire from the rocks over and through which they travel all of the elements that go to make these sodium sulphate brines. Rain water absorbs carbon dioxide from the air and in moving over the surface of the ground adds humic acids which make possible a ready solution of the calcium and magnesium carbonates found in the magnesian limestones and caliche. Where such waters seep into a porous body of gypsum, accumulating small amounts of sodium chloride, potassium, and boron in their travel, an exchange takes place in which the insoluble constituents combine to precipitate and the soluble salts continue on in solution. Thus in this assemblage of mineral matter, calcium carbonate and calcium suphate are deposited and as the process continues the concentration of the soluble salts progresses. With the elimination of calcium from the concentrating brine boron may accumulate and remain in solution as the soluble sodium borate.

So far no secondary sulphate minerals have been found in association with the brines in the gypsum beds. Either the concentrations of mineral matter never reached the stage at which minerals containing sodium sulphate could form, or such beds of the sulphate as might exist have not been penetrated by the drill. Deposits of sodium sulphate minerals would serve as a reserve in the economic utilization of the brine and as the present supply is withdrawn generate new brines more rapidly than the primary process could produce them.

OCCURRENCES OF BORON

The following is a brief preliminary outline of the possible sources for boron in this area: (1) the boron may have come from igneous emanations; (2) it may have been derived from decayed organic matter; (3) it may be residual from the potash-rich parts of the Salado formation; or (4) it may be disseminated in minute quantities throughout the upper Permian deposits.

The fact that the water of the Pecos River is now known to contain appreciable quantities of boron, both above and below Carlsbad, indicates that boron is not an uncommon element in this area. The Pecos River is unique in that it is divisible into two sections. The flow of water in the section above Avalon Dam may at certain periods be completely diverted for irrigation purposes. A dry channel then intervenes between the dam and the springs near Carlsbad. Here the river is regenerated by these springs, which supply water from the Capitan and Carlsbad limestones. The waters of both sections of the river are known to contain boron. Sufficient evidence is not yet at hand to reach a definite conclusion, but it seems likely that this boron is coming from minute disseminations of the element in the Permian sediments of the valley.

PROSPECTIVE AREA

From the evidence derived from the present stage of prospecting and an interpretation of the geologic relation certain deductions may be made regarding the potential prospecting area for sodium sulphate brines. It seems probable that the brines are the accumulations of the dense derivatives of percolating ground water through gravity differences and that they are retained in traps which temporarily at least preserve these concentrations from flushing by normal ground-water circulation. These brines are therefore considered as residual accumulations by differential gravity, a process relatively unique in the concentration of economic mineral matter in a dissolved form.

The materials essential to the formation of such a brine are dolomite and gypsum with contained accessories, chief among which is halite. The place of lodgment of these brines is at or near (above) the surface of alteration of anhydrite in the Castile formation to gypsum where this surface is not more than 100–300 feet below the ground surface. The prospecting area for sodium sulphate brines is then likely to be circumscribed by a line that follows the Pecos River northward from Pecos, Texas, to Cass Draw, then westward to the Barrera and southward along the outcrop of the base of the Castile formation to Seven Heart Gap, where it turns eastward along the north side of the

Apache Mountains to Pecos, Texas. The area between Cass Draw and the Barrera is probably flushed out by a more active ground-water circulation. The place where ascending circulation of ground-water feeds springs along the Pecos River is a likely terminus for sodium sulphate brines on the eastern side of the area. East of the river the anhydrites of the Castile formation remain unaltered and those of the Rustler formation are less likely to be changed. In the area of Nash Draw a strong sodium chloride brine is present in the basal part of the Rustler formation. The southern boundary including Toyah Lake, between Pecos, Texas, and the Apache Mountains, is less easily defined and may extend south to the margin of the Cretaceous outcrops. This preliminary outline crudely defines a hunting ground for sodium sulphate based upon the proposed concept of the origin of these brines. The area embraced is approximately 3,500 square miles of which 500 square miles are in New Mexico (Fig. 1).

Prospecting for sulphate brines west of the Pecos River is quite a different undertaking from that on the Llano Estacado for there the brines or shallow beds of salts occur beneath lake basins which can easily be located on the surface. West of the Pecos the sulphate-brine areas so far discovered have no apparent relation to the topography of the country, nor should they have if the formation of a trap by subsurface alteration of the anhydrate is largely a matter of chance. If the ground-water circulation follows the pattern of a valley system, as it often does in arid country, then one would be led to suspect that the chances are better for the discovery of residual brines beneath the broad divides than in the draws and valleys. This is a speculation now lacking the evidence necessary for a confirmation.

PRODUCTION OF SODIUM SULPHATE IN SOUTHWESTERN STATES

New Mexico.—To date no natural sodium sulphate has been produced commercially in New Mexico. For some years past deposits have been known to exist in many places, notably in the Estancia Valley and in the Tularosa Basin. In 1919 and again a few years ago efforts were made to develop Lake Lucero in the Tularosa Basin which lies between the White Sands and the San Andres Mountains. The projects were abandoned without record of production. Unless a local market can be established, freight rates are likely to prevent commercial success.

Arizona.—The Tertiary sediments of the Verde River Valley in Yavapai County, Arizona, contain deposits of gypsum, salt, and sodium sulphate. A large quantity of sodium sulphate has been produced from deposits of thenardite by the Arizona Chemical Company,

a subsidiary of the American Cyanamid Company, but in 1934 operations were discontinued and for the time being Arizona has ceased to be a producer of natural sodium sulphate. High freight rates and competition in outside markets are believed to have caused abandonment of the project.

Texas.—Prior to 1933 no natural sodium sulphate had been produced and marketed from either Texas or New Mexico. In 1933 after 2 years of preliminary investigation and testing the Ozark Chemical Company of Tulsa, Oklahoma, produced 2,000 tons from the brines of Soda Lake in southern Ward County, Texas. The lake and the plant are situated about one mile east of the Monahans-Fort Stockton highway, 11 miles south of Monahans which is the shipping point on the Texas and Pacific Railway (Fig. 1). Production has been steadily increased and 20,000 tons were produced and shipped in 1939.

Brines from depths of about 30 and 80 feet are pumped to the surface. The weaker brine from the 30-foot stratum is spread upon the playa of the lake where it leaches the crystalline surface salts and is further concentrated under favorable weather conditions. It is then pumped through a series of ammonia exchangers where hydrous sodium sulphate is chilled and progressively crystallized and filtered out. The salt is next exposed to a submerged gas flame in a retort where it is converted to the anhydrous form, and is then dried and stored. The waste brine, essentially magnesium chloride, is discharged into an outlying depression. The plant has an annual capacity of more than 30,000 tons of high-grade anhydrous sodium sulpahte.

The Arizona Chemical Company of New York, previously mentioned, began operations in Texas in 1937 and produced the first sodium sulphate to come from the High Plains lakes of the Llano Estacado. Plants were erected 10 miles east of Brownfield in Terry County and 8 miles west of O'Donnell in Lynn County, Texas (Fig. 1) Production has steadily increased, and in 1939 the enlargement and improvement of the plants doubled the 1938 production.

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GEOLOGICAL NOTES

DEVONIAN AND MISSISSIPPIAN INLIERS OF SOUTHWESTERN PENNSYLVANIA[1]

WILSON M. LAIRD[2]
Grand Forks, North Dakota

This paper reports progress on a study of the Upper Devonian and lower Mississippian rocks exposed in the anticlinal inliers in southwestern Pennsylvania. At a later date a more detailed report covering the stratigraphy of these inliers will be published. This study was made possible through a generous grant awarded by the American Association of Petroleum Geologists to whom grateful acknowledgment is given. For assistance in the field and laboratory, the writer wishes to thank Fred. I. Mason of Ohiopyle, Pennsylvania, and Kenneth E. Caster and Walter H. Bucher of the University of Cincinnati. The purpose of this study was three-fold: (1) to determine the exact age of the Devonian and Mississippian rocks of these areas and their relationship to studied sections in northwestern Pennsylvania, the Allegheny Front and the Broad Top area; (2) to determine the mode of origin and facieologic nature of the Devonian sequence; and (3) to determine, if possible, the age of the basal "Pocono" of western Pennsylvania.

Charles Butts in 1908, on the basis of faunal studies, identified the exposed Devonian beds along the National Road (U. S. Route 40) over Chestnut Ridge as Conewango in age. Recently Willard (1933 and 1939) cast some doubt on this determination of Butts and assigned these beds to the Cayuta (lower Chemung). This was essentially the conclusion reached by J. J. Stevenson in 1878 when he studied these beds for the Second Geological Survey of Pennsylvania. This age assignment by Willard precipitated a discussion (1935) during which it was brought out that these beds were assigned by Chadwick to the Canadaway while Caster reiterated Butts' 1908 conclusion. This present study has, on the basis of faunal, lithologic, and stratigraphic evidence, upheld Butts' and Caster's conclusions as to the Conewango age of these beds. It has been determined by direct comparison that the faunas of the Upper Devonian of the inliers correspond most closely with those of the Venango stage of the Conewango series of northwestern Pennsylvania. The Oswayo (Riceville) shale which overlies

[1] Manuscript received, November 25, 1940.

[2] University of North Dakota.

the Venango stage in northwestern Pennsylvania has not been positively identified in the southwestern Pennsylvania inliers although it seems highly probable that it is present but not recognized due to different facieologic conditions. For the first time, marine beds underlying the Devonian redbeds in the inliers have been recognized and tentatively correlated, on the basis of faunal evidence, with the Conneaut (Chadakoin) stage of northwestern Pennsylvania.

The best and most complete exposure of the Upper Devonian studied is exposed in the Youghiogheny gorge through Laurel Hill where the exposed Devonian sequence is 1,079 feet thick. This figure, which includes the redbeds as well as the marine sequences above and below the reds, may be somewhat inaccurate due to the locally severe eastward thrusting in the red sequence. At Summit, on the crest of Chestnut Ridge, the exposed Devonian totals about 317 feet while in the Youghiogheny gorge through Chestnut Ridge the exposed Devonian is 542 feet thick.

The facieologic relationships shown in the inliers are similar to those of northwestern Pennsylvania. In the inliers, the marine Upper Devonian consists of a marine magnafacies belt, similiar to the Big Bend magnafacies of northwestern Pennsylvania. Into this marine magnafacies, tongues a westward extension of the Catskill red magnafacies which replaces the marine beds on the northeast, east, and southeast. By plotting available surface and well-record data, it has been possible to add further refinement to the paleogeography of the Penn-York embayment in which most of the Upper Devonian and lower Mississippian sedimentation of western Pennsylvania took place. The well-record data show that the redbeds extend farther into West Virginia than has hitherto been supposed, thus extending the limit of the "Catskill" delta in that direction.

By far the most interesting development of this study was the finding of fossiliferous Mississippian beds in the base of the "Pocono." Two separate stratigraphic units which are correlatable over much of western Pennsylvania have been delimited in the base of the "Pocono" of the inliers. In ascending order these are, the Cussewago sandstones and shales (about 50–140 feet thick) and the Berea or Corry sandstone (about 40 feet thick) of the basal Oil Lake series. By means of faunal studies, it has proved possible to correlate the basal division (Cussewago stage) with the basal "Pocono" beds at Johnstown, Altoona, the Broad Top area, and northwestern Pennsylvania. The basal Mississippian beds from Altoona southward to U. S. Route 30 are so alike faunally and lithologically and agree so well stratigraphically with the Riddlesburg shale of the basal "Pocono" of the Broad Top area that

the name, Riddlesburg shale, has been extended to cover these basal Mississippian beds along this part of the Allegheny Front.

TABLE I

STRATIGRAPHIC UNITS OF LOWER MISSISSIPPIAN AND UPPER DEVONIAN OF SOUTHWESTERN PENNSYLVANIA

Mississippian system
- Kinderhook series
  - Shenango stage
  - Meadville stage
- Oil Lake series
  - Berea stage
  - Cussewago stage

Devonian system
- Conewango series
  - Riceville stage (tentatively identified in southwestern Pennsylvania)
  - Venango stage
- Chautauquan series
  - Conneaut stage (tentatively identified in southwestern Pennsylvania)
  - Canadaway stage
- Senecan series
  - Chemung stage
  - Naples ("Portage") stage
  - Genessee stage

$\left.\begin{array}{l}\text{Canadaway stage}\\ \text{Senecan series}\\ \text{Chemung stage}\\ \text{Naples ("Portage") stage}\\ \text{Genessee stage}\end{array}\right\}$ not exposed in the inliers

This study has brought out the fact that as far as western Pennsylvania is concerned, the basal "Pocono" is Mississippian regardless of the age of the "Pocono" elsewhere. When an isopach map of the reported occurrences of the "Pocono" was drawn, it was found that there are in Pennsylvania two main troughs of "Pocono" deposition. One area centers just west of the Allegheny Front and the other just north of Harrisburg. Between these two areas and approximately along the line of the Appalachian structural front as delimited by Paul Price (1931) is a zone of thinning. The exact explanation of this phenomenon is not as yet forthcoming but two possible explanations present themselves. First, there may have been two troughs of deposition where Mississippian "Pocono" sediments were being deposited simultaneously while between them less deposition was taking place. Second, it is possible that the deposits of the eastern trough are actually a facies phenomenon of the Upper Devonian and thus do not enter the Mississippian paleogeographic picture.

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THIS MATTER OF ESTIMATING OIL RESERVES[1]

FREDERIC H. LAHEE[2]
Dallas, Texas

This article is addressed not only to those who prepare estimates of oil reserves, but also to those who discuss and compare and use these estimates. It refers only to proved and partly proved areas.

Underground oil reserves are estimated for various reasons and by different methods. Estimates may be sought for an individual property or for a group of properties, or for a pool, or for a group of pools in a region. However, basically, estimates for the larger divisions must depend on estimates for the individual properties that comprise the area of an oil field. The quantity of oil present beneath a single property, or a group of properties, may be estimated for purposes of sale or purchase, or for various other reasons. No well may have been drilled on the land, or only one or possibly a few wells may have been drilled on it, or it may have been completely "drilled up." Unless the property has been completely drilled, certain assumptions must be made on the undrilled part, based on the part which *is* producing, or based on adjoining property which *is* producing. As a matter of fact, probably most estimates for ordinary purposes of appraisal relate to properties not fully drilled.

Oil reserves may be figured (a) by the old method of decline curves, or (b) by multiplying together a number of factors which have been individually studied and measured with care, or (c) by detailed analysis of production history (including data on gas-oil ratios, bottom-hole pressures, *et cetera*), and projection of this history into the future. Under (b) the factors used include porosity, permeability, sand thickness, and areal extent, and also the so-called "recovery factor" (percentage of fluid likely to be delivered from the total content of the pore space). Obviously there is room for considerable difference in the figures and estimates used; yet, when the basic figures are agreed on, generally there is a fair degree of similarity between the final results obtained by different workers.

[1] Manuscript received, November 25, 1940.

[2] Chief geologist, Sun Oil Company.

This statement may seem to be out of accord with certain widely divergent published estimates for groups of pools, that is, for regions. It is mainly these to which the present note refers. The big discrepancy sometimes observed is due to two entirely different methods of estimating reserves in newly discovered pools. According to one method, the porosity, recovery, and sand thickness factors found in the discovery well are multiplied into the *total* area of the pool as estimated from the geological or geophysical picture of the structure with which the pool is associated. In other words, if the indications are that oil production, discovered in one well (or a few wells) will eventually be obtained from, let us say, 5,000 acres on a given structure, this area of 5,000 acres is included in the estimate for this pool. On the other hand, the second method of figuring this reserve allows only an area which can safely be regarded as proved for production on the basis of the *known* geological habit of the region. Thus, a larger area would be regarded as proved by one well, or a few wells, in a region surely underlain by a blanket sand than in a region where sands, or porous zones in limestone, are likely to lense out. The more complicated the structural and stratigraphic conditions are thought to be, the smaller is the area which can logically be considered as proved where development of the pool is incomplete. In this second method, new area is added to the field, year by year, as drilling progresses. The first of these might be called the *probable-area method;* the second, the *proved-area method.*

The probable-area method is the one often applied in calculating reserves on incompletely developed *properties.* Consequently, those who are called upon to prepare such estimates are apt to follow a similar procedure in figuring oil reserves in *pools* that have not been fully drilled.

The proved-area method is conservative and relatively safe and free from the danger of making large errors. It is definitely a method for estimating *proved* reserves, not for stepping out too far into the unknown. It is a method which, with reasonably active wildcatting and development, is likely to show larger increments in reserves through *extension* of discovered oil territory than increments from new discoveries. In the end the estimates made by both of these methods for a given pool may turn out to be close, but early in development they may be very different.

It is our earnest advice and recommendation that all those who make estimates of oil reserves for public presentation (written or oral) be careful to explain which of the two methods (probable-area or proved-area) was employed. No long description would be necessary. A simple statement would suffice to the effect that either (1) unde-

veloped properties or pools have been assigned the whole area from which they will probably eventually produce oil (from whatever sand or sands are being appraised), or (2) only a limited area has been allowed where a property or a pool has not been sufficiently drilled to *prove* how far production may extend. And we would urge, further, that authors of papers and speeches contributed under the auspices of the Association be *required* to include this kind of statement, and that the editorial staff be instructed to see that this be done before publication.

Our only reason for offering these recommendations is that there may be less misunderstanding, among geologists and the public at large, of the significance of oil-reserve figures and better understanding of why these figures sometimes differ so widely for a given territory.

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DISCUSSION

WHERE SHOULD YOUNG GRADUATES IN PETROLEUM GEOLOGY ACQUIRE FIELD EXPERIENCE?[1]

F. H. LAHEE[2]
Dallas, Texas

On pages 2047 and 2048 of this *Bulletin* (Vol. 24, No. 11, November, 1940), David A. Dunn, in referring to past articles on the question which heads this note, makes a very interesting suggestion, namely, that several universities offer a coöperative geological field course. Such a course would involve investigations in each of several selected districts, and instruction under several teachers, each in his own province. It would probably involve rather extensive travel, but if transportation could be arranged economically, this would add to the value of the training. It seems to me that Mr. Dunn's suggestion merits very careful analysis, for it might be made feasible.

[1] Manuscript received, November 26, 1940.

[2] Chief geologist, Sun Oil Company.

Houston Chamber of Commerce

Statue of General Sam Houston at Hermann Park, Houston. General Houston led the early Texans to victory in the struggle of Texas to obtain independence from Mexico in 1836. General Houston helped establish the new Republic of Texas, and served as its first president.

The twenty-sixth annual meeting of the Association will be held at the Rice Hotel, Houston, April 2, 3, and 4, 1941.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

PROCEEDINGS OF THE FLORIDA ACADEMY OF SCIENCES FOR 1939

REVIEW BY ROBERT B. CAMPBELL[1]
Tampa, Florida

Proceedings of the Florida Academy of Sciences for 1939, Vol. 4. Published by the Academy (Gainesville, Florida, August, 1940). 310 pp.

This, the fourth volume of the Florida *Proceedings*, though somewhat tardy in appearance, represents a distinctly forward step for the Academy's publications. It is made up of 310 pages of miscellaneous papers of scientific interest, just twice the number of pages in the 1938 volume. Several articles in the 1939 volume may be of special interest to geologists. They are the following.

"Studies of Foraminifera from Seven Stations in the Vicinity of Biscayne Bay," by Sidney A. Stubbs
"Pteridophytes of Florida" (abstract), by Mary B. Diddell
"Outline of the Geological History of Florida," by Robert B. Campbell
"The Reaction of Magnolia, Scrub Live-Oak, Slash Pine, Palmetto and Other Plants to Dune Activity on the Western Florida Coast," by Herman Kurz
"A Marine Biological Laboratory on the Gulf Coast of Florida," by A. E. Hopkins

This last-named article is a description of a new station at Pensacola and includes an invitation to those making significant marine investigations to take advantage of the facilities there. Though the station is primarily to study fisheries problems, other problems, such as ecology *et cetera*, may be studied there. The article by Stubbs lists sixty-one species of Foraminifera representing twenty-three genera (the Miliolidae being predominant) collected on the southeast coast of Florida, with a discussion of their habitat. Stubbs discusses the uses of such studies as this for stratigraphy and paleogeography.

Campbell's paper includes a description of eight wells significant in the study of Florida's stratigraphy and outlines the history of the state's geologic theater since late Paleozoic time.

Mrs. Diddell's abstract discusses ferns and hints at some connection between West Indian forms and those on the original Oligocene Island in Florida.

Dr. Kurz, being a botanist, naturally emphasizes the behavior of plants in dune areas, but his incidental discussion of the dunes themselves is a contribution to the literature of geomorphology in Florida.

[1] Peninsular Oil and Refining Company. Manuscript received, November 15, 1940.

Editor's note.—Mr. Campbell modestly refrains from mentioning the fact that his paper was awarded the Achievement Medal by the Council of the Society. This Achievement Medal of the Florida Academy of Sciences is given by Phipps and Bird of Richmond, Virginia, and is awarded by the Council to the paper which in their estimation attains the highest rating of scientific value, among the papers presented at the annual meeting.

SEDIMENTARY PETROGRAPHY, BY H. C. MILNER

REVIEW BY W. H. TWENHOFEL[1]
Madison, Wisconsin

Sedimentary Petrography, by H. C. Milner. xxiii+666 pp., 100 text figs., 52 pls. Thomas Murby and Company, London, England; Nordeman Publishing Company, New York (1940). Price, $10.00.

This third edition of Milner's *Sedimentary Petrography* has been in large part rewritten and most chapters of the second edition have been expanded. The work has been enlarged from the xxi+514 pages of the second edition to xxiii+666 pages and from 148 to 152 plates and text figures. Some of the text figures of the second edition appear as plates in the third edition.

The increase in number of pages is much greater than is indicated by the figures given. The second edition has much blank space in the chapter giving description of minerals (VI) which was caused by beginning description of each mineral on a new page, thus leaving more or less blank space on the previous page. This practice has not been followed in the third edition and description of any mineral, except the first described, immediately follows that of the preceding mineral. The chapter on laboratory technique has been expanded from one chapter to four and from 55 to 153 pages. A new chapter on applied sedimentary petrology considers application of sedimentary petrography to the asphalt industry; building, ceramic, cement, and glass technology; criminology; fillers for woods and other substances; highway construction, medicine (industrial maladies); refractories; and water supplies.

The following tabulation in parallel columns shows the chief differences in the two editions.

2d Edition	*Pages*	*3d Edition*	*Pages*
I Introduction to the study of sedimentary rocks	9	I Introduction to the study of sedimentary rocks	11
II Surface and subsurface samples, storage and records	14	II Sampling of sedimentary rocks: Surface and subsurface samples, storage, and records	18
III Laboratory technique	55	III Laboratory technique	51
		IV Laboratory technique (continued): Mechanical analysis of sediments	35
		V Laboratory technique (continued): Further methods of mineral concentration	14
		VI X-ray, spectrum, fluorescence and microchemical methods of mineral analysis	19
IV Microscopical examination of sediments	26	VII Microscopical examination of sediments	39
V Quantitative data	11	VIII Methods of testing sedimentary rocks	24
VI Diagnostic properties of sedimentary rock minerals	152	IX Diagnostic properties of sedimentary rock minerals	101
VII The petrography of consolidated sediments	95	X The petrography of consolidated sediments	73

[1] Department of geology, University of Wisconsin. Manuscript received, November 18, 1940.

VIII The principles and practice of differentiation and correlation of sediments by petrographic methods	50	XI The principles and practice of differentiation and correlation of sediments by petrographic methods	47
IX Some examples of differentiation and correlation of sediments by petrographic methods	12	XII Some examples of differentiation and correlation of sediments by petrographic methods	12
X The bearing of sedimentary petrography on paleogeographical problems	25	XIII The bearing of sedimentary petrography on paleogeographical problems	27
XI The application of sedimentary petrology to the study of soils and related superficial deposits	26	XIV The application of sedimentary petrology to the study of soils and related superficial deposits	26
		XV Applied sedimentary petrology	13

Each edition has several tables of appendices and each has extensive bibliographies, the latter more extensive in the third edition.

The descriptions of the minerals and sedimentary rocks in the new book are excellent, but little changed from those of the second edition. Illustrations of minerals are good and more minerals are figured than in the second edition. The printing seems better than in the second edition, and as the lines are not so close together, the third edition is more easily read than the second.

The reviewer considers this revision of *Sedimentary Petrography* the best work on the subject that has been published. The work is excellently balanced and the dimensions of the new book are also considered superior to those of the old, 6 by $8\frac{3}{4}$ inches as against 5 by $7\frac{3}{8}$ inches.

The book should be close at hand on the desk or work bench of every student concerned with sedimentary minerals and their method of study. Professor Milner deserves the thanks of sedimentationists for bringing this excellent work up to date. The only criticism the reviewer cares to make is that the cost of the book, $10.00, seems very high.

EXPLORATION GEOPHYSICS, BY J. J. JAKOSKY

REVIEW BY L. W. BLAU[1]
Houston, Texas

Exploration Geophysics, by J. J. Jakosky. xii+786 pp., 411 figs. Times-Mirror Press, Los Angeles, California (1940). Price, $8.00.

This book fills a long-felt need for a comprehensive and well documented textbook of exploration geophysics. Most of us who work in applied geophysics have been approached by young and old students of geophysics with the request that we inform them where they might find information about this or that method in published form. We have pointed out articles, but there was no textbook which adequately covered the field.

There are twelve chapters, covering magnetic, gravitational, electrical,

[1] Geophysics and production research, Humble Oil and Refining Company. Manuscript received, November 28, 1940.

seismic, geochemical, and geothermal prospecting methods, drill-hole investigations, physical principles applied to production problems, permit and trespass practices, and insurance. The geologic and economic background of exploration geophysics is discussed in a chapter of 37 pages.

The book abounds with references, in footnotes, to the literature. Lists of pertinent patents giving patent numbers, dates of issue, names of the inventors, and titles are appended at the ends of chapters. These lists appear to be comprehensive and will be used to good advantage in making patent searches.

The author pulled no punches when it came to incorporating mathematical developments. It appears to the reviewer, however, that a word of caution on the dangers which lurk in the application of mathematics to applied geophysics would have been in order. It is usually necessary to assume homogeneous conditions, or only a very small number of layers in mathematical problems or forego the much desired answer; nature was not kind and we find much heterogeneity and very, very many layers. Moreover, most problems do not have unique solutions, even when homogeneity and two or three layers are assumed.

Highly technical material, directions for the use of instruments, and instructions for recording and evaluating data, are given in small print. In the reviewer's opinion, continuity has not always been preserved, so that one can not recommend that the novice in geophysics may safely skip the small print.

There are many illustrations; the layman will appreciate the photographs of equipment in field use.

The book is well written and shows careful proofreading. A few awkward or misleading statements should, however, be corrected in later editions. Examples are: "The magnetic exploration methods are one of the oldest of the applied geophysical methods," p. 53; "Oscillations of the magnet system are *dampened* . . . " [italics by reviewer], p. 93. Credit should have been given M. M. Slotnick on p. 479, first footnote. "Porosity" measurements are discussed on pp. 683 and 685. On p. 693, we read: "Alteration of the physical properties of a porous stratum by changes in the liquid which permeates it furnishes a parameter which is indicative of the porosity of the stratum." Permeability is meant where porosity is used. P. 694 abounds with "porosities" where no more than a measurement of potential can possibly be meant. It is time that we were unlearning the service-company advertising misinformation which implies that porosity or permeability can be measured electrically in bore-holes. "Porosity data" appears on p. 699.

The old, as well as the new, exploration methods are discussed in sufficient detail to enable the reader to appraise and use them. The chapters on geochemical and geothermal methods are about as complete as can be expected at this time, when one considers the fact that these procedures are new and have not been disclosed fully in the literature; few patents have been issued. The new advances in electrical prospecting, also, are treated comprehensively and sympathetically. The old exploration methods, magnetic, gravitational, and seismic, are covered in sufficient detail that the book can be used as a guide in the application of these techniques.

In the opinion of the reviewer, this treatise ought to be required reading for all geophysicists and students of geophysics, pure and applied, and can be highly recommended to all who are interested in this fascinating subject. The author deserves unstinted praise and gratitude for his labors.

INTERNAL CONSTITUTION OF THE EARTH, EDITED BY B. GUTENBERG

REVIEW BY ROBERT L. BATES[1]
Midland, Texas

Internal Constitution of the Earth, edited by B. Gutenberg. Published by McGraw-Hill Book Company, New York (1939). 413 pp., 27 text figs., 69 tables. Price, $5.00.

Internal Constitution of the Earth is Volume VII of a series of monographs which when complete will constitute an exhaustive treatise on the physics of the earth. The series, which is being prepared under the auspices of the National Research Council, already includes volumes on volcanology, the figure of the earth (gravity, isostasy, tides, *et cetera*), meteorology, the age of the earth, oceanography, and seismology. An eighth volume, on terrestrial magnetism and electricity, has just been issued.

Each of the volumes is written by one or more acknowledged leaders of thought and experiment in the specific field. Beno Gutenberg, professor of geophysics at the California Institute of Technology, edits *Internal Constitution of the Earth* and contributes several chapters himself. Other contributors include six geophysicists, one seismologist, and one geologist.

Questions of the earth's interior can be answered, if at all, only through the medium of geophysics, the term being used in a broad sense to refer to that "boundary science" which overlaps on the domains of astronomy, geology, physics, chemistry, and seismology. Only trained scientists of considerable intellectual ability and imagination are qualified to reconstruct rationally the history of the earth's origin and the nature of its interior. In a book such as this one is, covering a wide range of precise knowledge, it is to be expected that sections dealing with specialized fields and written in specialized terms will be difficult to understand for the person who is not trained in such fields. A few chapters of this volume are rather involved and require a knowledge of physics and mathematics not possessed by the average reader. Several other chapters, however, are lucidly written and treat of subjects which all persons with a curious mind or a speculative bent must find intensely interesting. These chapters include Harold Jeffreys' on the earth's origin, R. A. Daly's on relevant facts and inferences from field geology, Gutenberg's on the development of the earth's crust, and the late H. S. Washington's on the crust and its relation to the interior.

As Jeffreys points out in an early chapter, the study of the earth as a whole is made difficult by two obvious facts: there were no human witnesses when the earth was formed, and man is unable to penetrate into the earth more than a tiny fraction of its radius. These two facts, taken alone, might at first glance make it appear impossible for man to do anything further than speculate at random about such a tremendous subject. But, in legal procedure, the fact that a jury was not present at the scene of a crime does not in any sense mean that it can not obtain some very precise evidence as to what happened. It is a case of finding out what occurred on a previous occasion from evidence now at hand. Such is exactly the position of a geophysicist speculating about

[1] The Texas Company. Manuscript received, November 25, 1940. Reviewer's present address is New Mexico Bureau of Mines, Socorro, New Mexico.

the origin and nature of the earth. His evidence comes from many sources, some plain, some involved and obscure. Behavior of earthquake waves as they pass through the earth; the tidal effect of the sun and moon on the solid parts of the earth; the amount and type of molten rock which wells up from the earth's interior; the distribution of the continents and ocean basins on the earth's surface—all these and many more bits of evidence help the geophysicist to piece together his picture of the interior of the globe.

Many people are prejudiced against any science which deals in great figures—tremendous distances in astronomy, vast lengths of time in geology, inconceivable minuteness in atomic physics—because so frequently a scientist's results are announced without any accompanying report of how he arrived at those results. The unadorned statement that a certain star is 200 light-years distant from the earth is likely to provoke resentment and a feeling that the astronomer is a show-off, unless some evidence is given as to how such a great figure was determined. The present reviewer wishes to state a few of the results of modern geophysical work reported in *Internal Constitution of the Earth*, without, for reasons of space, giving the factual data backing them up. The reader is notified, however, that cogent and logical reasons for these statements are set forth in this book.

It is believed that the earth has existed as a separate body for perhaps as long as 3,000 million years. Apparently it was one of the products of the breakup of the sun through the tidal action of a passing star. It is indeed possible that there was actually a collision between the sun and another star, which disrupted the former and produced the planets of our solar system and their satellites.

Among many other geological data bearing on the question of the earth's interior, R. A. Daly lists the inability of geologists to find any important body of rock which may be regarded as planetesimal in origin. Hence he makes the assumption that the earth was not built up to its present size by accretion of rock material from space by gravitation. Daly's chapter makes clear some points that may have been forgotten by geologists who spend their lives in the study and interpretation of sedimentary rocks. The undeniable fact stands out that sedimentary rocks make up only about 5 per cent of the earth as a whole, while such materials as coal, ores, surface soils, and petroleum are utterly negligible when considered from the planetary standpoint. World-geologists, if one may speak of men like Daly as such, are concerned mostly with igneous rocks and their minerals, theories of elasticity and shear as applied to rock masses, transmission of earthquake waves, and the like.

Gutenberg states that it seems probable that the heat within the earth is generated by a combination of radioactivity and chemical processes. It is no longer believed that the earth was once a molten liquid and that the present surface is a solidified crust resting on a still liquid interior. Many other valid conclusions are possible when the evidence presented in this book is analyzed. The mere enumeration of results, however, is of value only as a stimulus leading toward examination of the ingenious way in which knowledge is accumulated and classified and evidence piled up to apply to the baffling questions of earth origin and internal composition. This last is the truly fascinating aspect of theoretical geophysics.

Some of the chapters in the book contain summaries. The entire work is summarized by Gutenberg in five pages at the end of the volume. There is a

bibliography following each chapter. An author index and a subject index are included. An appendix gives (1) frequently used astronomical and geodetic constants, such as the equations for the earth's flattening and for the eccentricity of its orbit, and (2) conversion tables of c.g.s. units—in which the numerical figures are given throughout the book—to those of other systems.

Perusal of the bibliographies reveals what a great literature on geophysics already exists in German. Germany has until recent years been the center of this type of earth research. Gutenberg and his co-authors have done an excellent job of writing, in a readable manner, the first authoritative treatise on the interior of the earth to appear in English.

RECENT PUBLICATIONS

CANADA

*"Preliminary Map, Wapiabi Creek, Alberta," by B. R. MacKay. *Canada Geol. Survey Paper 40-13* (Ottawa, 1940). Blue-line paper print showing areal and structural geology of Devonian-Upper Cretaceous rocks on 100-foot contour topographic base. Scale: 2 inches = 1 mile. Sheet, 27.5×40.5 inches. Another sheet, 40×23 inches, shows 3 structure sections on horizontal and vertical scale of 1 inch = 0.5 mile. Both folded in envelope cover. Price, $0.10.

*"First Large Scale Attempt to Develop Alberta's Bitumen Sands," by N. R. O'Dell. *Canadian Oil and Gas*, Vol. 1, No. 5 (Toronto, November, 1940), pp. 5 and 30; 1 photograph.

*"Structural Geology and Commercial Possibilities of Brazeau Area," by J. O. G. Sanderson. *Ibid.*, pp. 15–19; photographs.

CALIFORNIA

*"Geology of the Oxnard Plain," by Robert B. Moran. *California Oil World*, Vol. 33, No. 21 (Los Angeles, November, first issue, 1940), pp. 16–19; 1 map, 2 geologic sections.

*"Supplementary Report on Fruitvale Oil Field," By Robert H. Miller. *California Oil Fields*, Vol. 24, No. 1, July, August, September, 1938 (San Francisco, November, 1940), pp. 24–29; 4 pls.

*"Gas Fields of Southern San Joaquin Valley," by E. J. Kaplow. *Ibid.*, pp. 30–50; 12 pls. Includes Buttonwillow, Semitropic, Trico, Buena Vista Lake gas fields.

CHINA

*"Das chinesische Seilbohren, das älteste Bohrverfahren der Welt" (The Chinese Hand-Rope Drill, the Oldest Drilling Method in the World), by F. Müller, *Oel und Kohle*, Vol. 36, No. 39 (Berlin, October, 1940), pp. 371–75; 14 figs.

FLORIDA

*"Outline of the Geological History of Peninsular Florida," by Robert B. Campbell. *Proc. Florida Acad. Sci.*, Vol. 4, 1939 (Gainesville, August, 1940), pp. 87–105; 11 figs.

GENERAL

*"The Faunal Succession in the London Clay, Illustrated in Some New Exposures near London," by Arthur Wrigley. *Proc. Geologists' Association*, Vol. 51, Pt. 3 (London, October 31, 1940), pp. 230–45.

*"Some Geological Factors Concerning Our Future Oil Reserves," by A. I. Levorsen. *Independent Petrol. Assoc. America Monthly*, Vol. 11, No. 7 (Tulsa, November, 1940), pp. 27–30. Paper presented at eleventh annual meeting of the I.P.A.A., Dallas, Texas, October 17, 1940.

*"Some Geological Factors and Future Oil Supplies," by A. I. Levorsen, *Oil Weekly*, Vol. 99, No. 12 (Houston, December 2, 1940), pp. 12–15.

*"Review of the Pelycosauria," by A. S. Romer and L. W. Price. *Geol. Soc. America Spec. Paper 28* (New York, December, 1940). 538 pp., 71 figs., 46 pls.

*"Well Logging by Radioactivity," by William L. Russell. *Oil Weekly*, Vol. 99, No. 10 (Houston, November 11, 1940), pp. 16–21; 2 photographs; 2 log charts.

*"Latest Thoughts on Origin of Oil," by W. A. Reiter. *Ibid.*, pp. 24–30.

*"Basic Principles in Acid-Treating Limes and Dolomites," by J. B. Stone and D. G. Hefley. *Ibid.*, pp. 32–44; 13 figs.

*"Temperature Survey in Oil Wells," by C. V. Millikan. *Amer. Inst. Min. Met. Eng. Petroleum Technology*, Vol. 3, No. 4 (New York, November, 1940). *A.I.M.E. Tech. Pub. 1258*. 8 pp., 9 figs.

*"Continuous Logging at Rotary Drilling Wells," by J. T. Hayward. *Oil and Gas Jour.*, Vol. 39, No. 27 (Tulsa, November 14, 1940), pp. 100–10; 8 figs.

*"Factors Affecting Reservoir Performance," by R. D. Wychoff. *Ibid.*, pp. 188–200.

*"Bibliography of Fossil Vertebrates, 1928–1933," by C. L. Camp and V. L. Vanderhoof. *Geol. Soc. America Spec. Paper 27* (New York, November 20, 1940). 503 pp.

ILLINOIS

*"New Pool in Prospect in Gallatin County, Illinois," by W. Farrin Hoover. *Oil and Gas Jour.*, Vol. 39, No. 27 (Tulsa, November 14, 1940), p. 87; 2 structure maps.

"Porosity, Total Liquid Saturation, and Permeability of Illinois Oil Sands," by R. J. Piersol, L. E. Workman, and M. C. Watson. *Illinois Geol. Survey Div. R. I. 67* (Urbana, November, 1940). 72 pp., 39 figs., 53 tables. Price, $0.15.

LOUISIANA

*"Central South Louisiana," compiled by *Oil and Gas Journal*, Vol. 39, No. 29 (Tulsa, November 28, 1940), pp. 58–59; map and sections in colors.

MISSOURI

*"New Species of Corals from the Bainbridge Limestone of Southeastern Missouri," by John R. Ball and Brandon H. Grove. *Amer. Midland Naturalist*, Vol. 24, No. 2 (Notre Dame, Indiana, September, 1940), pp. 382–404; 3 figs., 4 pls.

*"New Species of Silurian Dalmanites from Southeast Missouri," by John R. Ball and David M. Delo. *Ibid.*, pp. 405–10; 1 pl.

MONTANA

*"The Geology and Vertebrate Paleontology of the Fort Logan and Deep River Formations of Montana. Part I, New Vertebrates," by Harold E. Koerner. *Amer. Jour. Sci.*, Vol. 238, No. 12 (New Haven, Connecticut, December, 1940), pp. 837–62; 7 pls.

OKLAHOMA

"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Part 4, Townships 24 and 25 North, Ranges 10 and 11 East," by L. E. Kennedy, J. D. McClure, H. D. Jenkins, and N. W. Bass. *U. S. Geol. Survey Bull. 900-D* (1940), pp. 131–71; 1 pl. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.35.

*"South Central Oklahoma." In "Well Logs and Field Data of Active Oil Areas," compiled by *Oil and Gas Jour.*, Vol. 39, No. 27 (Tulsa, November 14, 1940), pp. 122–23; geologic map, logs, and stratigraphic column in colors.

PECHELBRONN

*"Die geologische und produktionstechnische Erschliessung und Entwicklung des Pechelbronner Erdölreviers seit 1920" (The Findings of Geology and Production Technique and the Development of the Pechelbronn District since 1920), by Wolfgang Richter. *Oel und Kohle*, Vol. 36, No. 39 (Berlin, October, 1940), pp. 367–69; 7 tables.

PENNSYLVANIA

"Petrology and Genesis of the Third Bradford Sand," by Paul D. Krynine. *Pennsylvania State College Bull. 29* (November, 1940). Price, $0.50. 126 pp., 35 figs. School of Mineral Industries, State College, Pennsylvania. Appendix contains quantitative data on drill cores from six wells.

ROCKY MOUNTAINS

*"Diastrophic Behavior around the Bighorn Basin," by Rollin T. Chamberlin. *Jour. Geol.*, Vol. 48, No. 7 (Chicago, October-November, 1940), pp. 673–716; 8 figs.

RUMANIA

*"Rumanian Wells in Overthrust Area Damaged by Earthquakes," by W. V. Howard. *Oil and Gas Jour.*, Vol. 39, No. 28 (Tulsa, November 21, 1940), pp. 10–11; 2 figs., 1 table.

TENNESSEE

"The Clays of West Tennessee," by George I. Whitlatch. *Tennessee Dept. Conservation Div. Geol.* (October, 1940). 356 pp., 10 pls., 38 figs.

TEXAS

*"A Study of Well Spacing, Sinclair-Moren Pool, Young County, Texas," by M. G. Cheney. *Amer. Inst. Min. Met. Eng. Petroleum Technology*, Vol. 3, No. 4 (New York, November, 1940). *A.I.M.E. Tech. Pub. 1253.* 4 pp., 1 fig.

*"Chapel Hill Field, Smith County, Texas," compiled by *Oil and Gas Jour.*, Vol. 39, No. 30 (Tulsa, December 5, 1940), pp. 26–27. Contains one development and ownership map.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 1 (JANUARY, 1941), P. 177

RESEARCH NOTES

ANNOUNCEMENT

Arrangements have been made whereby the report of F. M. Van Tuyl and Ben H. Parker, entitled "Time of Origin and Accumulation of Petroleum," will be published in the Colorado School of Mines Quarterly on April 1, 1941. This report presents the results of one of the investigations sponsored by the research committee and the authors have been working on the project during the past several years. It consists in part of answers to a large number of questionnaires which were sent out to a representative list of members and thus furnishes a cross section of opinion among petroleum geologists on many questions pertaining to the origin and migration of oil. In developing the answers to the questionnaires new factual data were submitted by many contributors with the result that much new material of interest will be found in the report. It is in the nature of a progress report and should be of interest and use to everyone interested in the problems of origin and accumulation of petroleum.

The report consists of approximately 185 printed pages and is being offered to Association members at a pre-publication price of $1.50, delivered. Send orders to the Department of Publications, Colorado School of Mines, Golden, Colorado.

A. I. LEVORSEN
Chairman, research committee

RESEARCH DINNER—ROUND TABLE DISCUSSION

As in previous years, the research committee will sponsor a dinner followed by a round table discussion on the evening preceding the opening of the annual convention at Houston. The dinner is scheduled for 6:30 to 8:00 P.M. and the discussion period from 8:00 to 11:00 P.M. on Tuesday evening, April 1. The topic of the evening discussion will be "Future Possible Oil Provinces of the United States and Canada." Each area which it is thought has future possibilities will be discussed briefly with the aid of slides, the object being to present an over-all picture rather than a large mass of detail. No attempt will be made to appraise the possibilities quantitatively or on a barrel basis nor will consideration be given as to the methods of exploration necessary to make the discoveries in the different areas. The material is being developed through committees from various geological societies most familiar with the prospective areas thereby giving it a wide authority. It is hoped the meeting will be of interest and profit to our membership.

A. I. LEVORSEN
Chairman, research committee

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 1 (JANUARY, 1941), PP. 178-183, 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ASSOCIATE MEMBERSHIP

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M. N. Bramlette, Ian Campbell, W. S. W. Kew
Vincent Eugene Hanes, Urbana, Ill.
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W. C. Krumbein, D. Jerome Fisher, Carey Croneis
Ruhollah Y. Karubian, Berkeley, Calif.
J. Harlan Johnson, F. M. Van Tuyl, C. A. Heiland
Robert Joseph Minton, La Barge, Wyo.
Rolland W. McCanne, R. H. Beckwith, Horace D. Thomas
Walter Sigfred Olson, Bartlesville, Okla.
Homer H. Charles, Rycroft G. Moss, Hugh W. O'Keeffe
John Taylor Sinclair, Jr., Los Angeles, Calif.
Joseph Jensen, Harry P. Stolz, H. J. Steiny
Frank Vincent Stevenson, Chicago, Ill.
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FOR TRANSFER TO ACTIVE MEMBERSHIP

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C. R. McKnight, J. D. Aimer, A. E. Oldham
Theodore L. Tapp, Maracaibo, Venezuela, S.A.
John G. Douglas, Chester A. Baird, P. E. Nolan

TWENTY-SIXTH ANNUAL MEETING, HOUSTON APRIL 2-4, 1941

A feature of the twenty-sixth annual meeting of the A.A.P.G., which is to be held at the Rice Hotel, Houston, Texas, April 2-4, 1941, will be the Association research committee's annual dinner and subsequent round table discussion on "Future Possible Oil Provinces of the United States and Canada." Research committee chairman Levorsen states that no attempt will be made to appraise the possibilities quantitatively or on a barrel basis. It is hoped that this will be a timely and valuable over-all presentation of

Courtesy of Houston Chamber of Commerce

Turning basin and part of 45-mile ship channel, Houston, Texas, adjacent to which are industries involving capital investment of more than $250,000,000, and employing thousands of workers.

possibilities that must be of great importance to the oil industry and to the Western Hemisphere in the near future. The dinner is scheduled at 6:30 P.M., and the discussion at 8:00 P.M., Tuesday, April 1, at the Rice Hotel.

Other meetings on April 1 will be those of the research committee conference groups, six of them convening separately on Tuesday afternoon. On Tuesday morning the standing committees of the Association hold their annual meetings. The business committee, composed of the district representatives and the members of the executive committee meets at 10:00 A.M., April 1.

The Society of Exploration Geophysicists will present its technical program on April 1, 2, and 3.

The Society of Economic Paleontologists and Mineralogists will be in session on April 3 and 4.

Alexander Deussen, chairman of the steering committee, has announced the following convention committee personnel.

GENERAL COMMITTEE

Alexander Deussen, *chairman*, 1006 Shell Building

R. L. Beckelhymer	L. P. Garrett	Wallace C. Thompson
Cliff Boles	Marcus A. Hanna	John M. Vetter
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EXHIBIT OF GULF COAST GEOLOGY

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MISSISSIPPI GEOLOGICAL SOCIETY FOURTH ANNUAL FIELD TRIP, DECEMBER 6–8, 1940

D. C. HARRELL
Jackson, Mississippi

Over the week-end of December 6–8, an extensive and instructive field trip was conducted by the Mississippi Geological Society in northern Alabama. The success of this trip was largely due to the leadership of Russell S. Poor of Birmingham-Southern College, who conducted the caravan of 40 cars and led the discussion by the use of a loud speaker attached to the leading car. He was assisted by Arthur Blair, chief geologist of the Tennessee Coal and Iron Company, and Robert Ross of the Tennessee Valley Authority. Geologists from Oklahoma, Texas, Louisiana, Arkansas, Mississippi, Alabama, Tennessee, West Virginia, Florida, and Georgia attended the field trip. They were given the opportunity to see the iron deposits in the vicinity of the Ishkooda Mine No. 11 and to study the entire stratigraphic section from the Conasauga limestone of the Cambrian system up through the Mississippian and Pennsylvanian systems in the vicinity of Birmingham.

At the close of the first day, the Southern Natural Gas Company acted as host to the party and later a banquet was held by the geologists and a group of prominent business men of Birmingham. Dr. Poor was in charge of the program and talks were made by Urban Hughes, president of the Society; Joe Dawson, chairman of the field trip committee; Arthur Blair, on "The Development of the Iron Industry in the Birmingham District"; Charles Blair, on "The Carbon Ratios of the Cahaba, Coosa and the Warrior Coal Fields"; Robert J. Riggs, research geologist of the Stanolind Oil and Gas Company, representing the petroleum geologists; and A. I. Levorsen, consulting geologist, on the program outlined by the research committee of the American Association of Petroleum Geologists.

Saturday morning, the group progressed northward from Birmingham across the Blount Springs dome in the Warrior Coal Basin and examined the Mississippian and Pennsylvanian beds in that area. Of special interest was the asphaltic sand near Hartselle in Morgan County and the geologic section at Monte Sano State Park near Huntsville.

Sunday, the trip down the Tennessee Valley included stops at the Wheeler and Wilson dams and Muscle Shoals. Many of the geologists who have done core-drill work for the oil companies were especially interested in the large core taken in the Warsaw formation at the base of the Wheeler Dam. This core is 36 inches in diameter.

The final stops for the trip were exposures of asphalt-bearing Bethel sandstone and Gasper limestone in Colbert County.

A guide book prepared for this trip showed the log of the route, a résumé of the formations exposed and the history of the oil development in the northern part of Alabama. Additional copies of this guide book are available from the secretary of the Society at $2.00 each, for those who were unable to attend the trip. Address D. C. HARRELL, secretary-treasurer, Mississippi Geological Society, Drawer 1490, Jackson, Mississippi.

ASSOCIATION COMMITTEES

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Henry A. Ley, San Antonio, Texas
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J. T. Richards	Fred H. Wilcox	O. A. Seager
J. Marvin Weller		H. V. Tygrett

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1941	1942	1943
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D. Perry Olcott	Bela Hubbard	John M. Hills
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Wendell P. Rand	T. E. Weirich	F. B. Plummer
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Harold N. Hickey	Hugh D. Miser	Robert M. Kleinpell
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Henry C. Cortes (1941), *vice-chairman, geophysics*, Magnolia Petroleum Co., Dallas, Tex.

Carey Croneis (1943), *vice-chairman, paleontology*, University of Chicago, Chicago, Ill.

1941	1942	1943
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	Earl A. Trager	B. B. Weatherby

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George S. Buchanan, *chairman*, Box 2199, Houston, Texas

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Arthur E. Brainerd	Frederic H. Lahee	E. Floyd Miller
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL 25, NO. 1 (JANUARY, 1941), P. 184

Memorial

HOWARD WALTER HANDLEY
(1905–1940)

Howard Walter Handley died in Memorial Methodist Hospital, Mattoon, Illinois, on the evening of October 24, 1940. Death was caused by leukemia with which he was known to have been afflicted for only a short time. He is survived by his wife Ella Mae, a 2-year-old daughter, Carla Jane, and his parents, Mr. and Mrs. William Handley, of Ness City, Kansas.

Handley was born near Forest City, Missouri, on May 14, 1905. He received grade-school and high-school education in Ness City, Kansas. In the fall of 1924 he matriculated at Washburn College in Topeka, Kansas, where he was active in football. He transferred to the University of Oregon in 1928 where he first became actively interested in geology. Here again he was a member of the football team. Upon receiving the B.S. degree in 1930, he elected to remain as a graduate teaching assistant, obtaining the M.S. degree in 1931. While in the University he was initiated into Kappa Sigma and elected to associate membership in Sigma Xi. His scholastic career was followed by 3 years of teaching high school at Bazine and Bucklin, Kansas, where he coached football and taught general science and mathematics. While at Bucklin, he met Ella Mae Rudd to whom he was married on Easter Sunday, 1934.

In June, 1934, Handley joined the staff of the Petty Geophysical Engineering Company, of San Antonio, Texas, and until November, 1937, was attached to seismograph parties operating in Texas, Oklahoma, and Kansas. At this time he entered the employ of the Magnolia Petroleum Company as a geologist. After a brief period in West Texas and New Mexico, he was transferred to Mattoon, Illinois, where he resided.

Handley was graced with a most pleasing personality and a fine sense of humor. His ability to handle more than his share in repartee won for him an envied position among his fellows. We who knew and worked with Howard Handley feel keenly the loss of a faithful friend and a very competent associate.

VERNER JONES

MATTOON, ILLINOIS
November 19, 1940

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 1 (JANUARY, 1941), PP. 185-192

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Kansas Geological Society had their first meeting as a Study Club Group, November 12, at Wichita, Kansas. The subject for discussion was the Viola formation of Kansas. Ten members of the Society prepared columnar sections of the Viola limestone as it appears in deep wells in different parts of the state. The state was divided into eleven districts and each district was discussed by one of the ten members selected to lead the discussion: Viola of Northeastern Kansas by F. B. CONSELMAN; Salina Basin, by R. A. CARMODY; Butler County, by H. E. REDMON; Sedgwick and Harvey Counties, by OLIVE HOFFMAN; McPherson and Reho Counties, by JOHN INKSTER; Ellsworth and Rice Counties, by ELIZABETH ISAACS; South-Central Kansas, by JAMES DANIELS; Stafford County, by W. C. IMBT; Pratt and Kingman Counties, by H. O. SMEDLEY; Northwestern Kansas, by ROBERT MEYER; and Southwestern Kansas, by JOHN INKSTER. In order to make the lithologic details stand out so that every one in the audience might appreciate them, they were painted in watercolors on the back part of log strips on a scale of 5 feet to the inch.

ROBERT L. CLARKE, of the Superior Oil Company, has been transferred from Wichita Falls to Midland, Texas.

MICHEL T. HALBOUTY, consulting geologist, talked before the Houston Geological Society recently on "Oil and Gas Stratigraphic Reservoir in the University Oil Field, East Baton Rouge Parish, Louisiana."

GEORGE R. PINKLEY, consulting geologist, discussed "The Productive Prospects of Northern Alabama" before the South Texas Geological Society at San Antonio, November 11.

J. A. ROGERS, formerly at Midland, has been promoted to the position of district geologist for The Texas Company at Pampa, Texas.

J. E. BRANTLY, president of the Drilling and Exploration Company, Los Angeles, California, is the first president of the American Association of Oil Well Drilling Contractors, recently organized to conduct an educational campaign, to provide means of discussing drilling methods, to promote studies to reduce drilling costs and simplify cost accounting, and to improve organization of accident-prevention work.

At the meeting of the Appalachian Geological Society at Columbus, Ohio, November 1, the following State geologists addressed geologists from Illinois, Indiana, Kentucky, Ohio, West Virginia, and Pennsylvania: DANIEL J. JONES, of Kentucky, "Summary of Recent Geologic Research in Kentucky"; PAUL H. PRICE, of West Virginia, "Geologic History of the Appalachian Area"; WILBER STOUT, of Ohio, "Historical Development of the Petroleum Industry."

C. W. TOMLINSON talked on "Structural History of Southern Oklahoma and Its Significance in North Texas," before the Ardmore Geological Society at Ardmore, Oklahoma, October 24.

J. FRENCH ROBINSON is the new president and director of the East Ohio Gas Company, Cleveland, Ohio. In 1936 he became president of the Peoples Natural Gas Company and the Columbia Natural Gas Company, at Pittsburgh, Pennsylvania.

FRANK BUTTRAM, independent operator of Oklahoma City, has been elected to the Oklahoma Hall of Fame.

E. DEGOLYER, consultant of Dallas, Texas, is giving a series of lectures in the geological department of the University of Oklahoma.

WM. R. CAMPBELL is now with the geophysical department of the Stanolind Oil and Gas Company after completing a year of graduate work in geology at the University of California, Berkeley. He is now working in the southern part of Louisiana. His present permanent address is 418 Thelma Drive, San Antonio, Texas.

L. C. SNIDER, president of the Association, for many years consultant to Henry L. Doherty, 60 Wall Street, New York City, author of *Earth History* and other geological texts, has accepted appointment as professor of geology at the University of Texas.

RALPH H. SOPER, of the Standard Oil Company of Indiana, Chicago, Illinois, died on September 23.

WARREN B. WEEKS, of the Phillips Petroleum Company, Shreveport, Louisiana, recently elected president of the Shreveport Geological Society, spoke before the Tulsa Geological Society on "Geology of the Schuler Oil Field, Union County, Arkansas," November 18.

THOMAS J. NEWBILL, of the Standard Oil Company of California, has returned from India, and may be addressed at 225 Bush Street, San Francisco, California.

EDWIN P. MATTHEWS, recently with the Mene Grande Oil Company, Maracaibo, Venezuela, has returned to the United States. His address is 817 North A Street, Wellington, Kansas.

RICHARD V. BROWNE has changed his address from Nicosia, Cyprus, to The Iraq Petroleum Company, Ltd., Haifa, Palestine.

HARRIS H. ALLEN, of the Phillips Petroleum Company, has been transferred from Shreveport, Louisiana, to Bartlesville, Oklahoma.

WILLIAM C. MORSE, Mississippi State geologist, spoke on "Paleozoic Rocks of Mississippi" at a recent meeting of the Mississippi Geological Society in Jackson.

ROBERT B. CAMPBELL, president of the Peninsular Oil and Refining Company, Tampa, Florida, has been awarded the Achievement Medal of the Florida Academy of Sciences for his paper presented to the last annual meeting, entitled: "Outline of the Geological History of Peninsular Florida."

CHARLES B. CARPENTER, of the United States Bureau of Mines, Department of Interior, spoke before the Dallas Petroleum Geologists, Dallas, Texas,

November 18, on "Measurements of Compressibility of Consolidated Oil-Bearing Sandstones."

A. I. LEVORSEN, of Tulsa, Oklahoma, chairman of the Association research committee, attended the annual meeting of the Pacific Section of the Association and subsequently lectured before the following groups: the Journal Club of the department of geology at the Stanford University, Palo Alto, California; the Geology Club of the California Institute of Technology at Pasadena, California; the Colorado School of Mines at Boulder, Colorado; and the University of Colorado at Denver, Colorado.

JOHN R. SUMAN, vice-president of the Humble Oil and Refining Company, Houston, Texas, has been elected president of the American Institute of Mining and Metallurgical Engineers, effective in February, 1941.

JOHN MCCAMMON and A. H. WADSWORTH, graduate students at the University of Texas, read papers on "Isopachous Map of the Austin Formation," and "Study of the Colorado River Delta of Texas," before the Houston Geological Society, November 12.

WALTER L. MCCLOY, JR., production engineer with the Standard Oil Company (Ohio), is stationed at Medina, Ohio.

WALTER H. HEGWEIN, formerly with the Astra Romana S.A., Campina, Roumania, is with the Caribbean Petroleum Company in Maracaibo, Venezuela.

W. L. RUSSELL, of Well Surveys, Inc., Tulsa, talked before the West Texas Geological Society, at Midland, Texas, November 28, on "Well Logging by Radioactivity."

C. E. NEEDHAM, president of the New Mexico School of Mines, Socorro, New Mexico, and director of the New Mexico Bureau of Mines and Mineral Resources, talked on "The Permian of Central New Mexico," before the West Texas Geological Society at Midland, Texas, November 23.

E. BERL, research chemist at the Carnegie Institute of Technology, Pittsburgh, addressed the Tulsa Geological Society, December 9, on "Rôle of Carbohydrates in the Formation of Bituminous Coals, Asphalts, Oils, and Natural Gas."

WALTER S. OLSON, of The Texas Company, has been transferred from Bakersfield, California, to 135 East 42d Street, New York City.

R. W. HARRIS discussed the Simpson formation at a meeting of the Shawnee Geological Society, Shawnee, Oklahoma, December 2.

EDGAR D. CAHILL has returned to active work with the Skelly Oil Company after an absence of a year because of illness. He has been transferred from the Shreveport, Louisiana, district office to the Evansville, Indiana, office.

The Ardmore Geological Society at Ardmore, Oklahoma, listened to W. J. HILSEWECK of the Gulf Oil Corporation, Forth Worth, Texas, talk on "The Walnut Bend Field, Cooke County, Texas," December 3.

A. LYNDON BELL, formerly at Alton, Illinois, is with the International Petroleum Company, Ltd., Guayaquil, Ecuador, S. A.

W. E. WRATHER, consulting geologist, talked to the Dallas Petroleum Geologists, December 2, on "The Rôle of Minerals in International Affairs."

EUGENE A. STEPHENSON, head of the petroleum engineering department at the University of Kansas, at Lawrence, has been elected chairman of the Petroleum Division of the A.I.M.E.

LEO HORVITZ, geophysicist of Subterrex, Houston, Texas, spoke on "Geochemical Well Logging," before the Fort Worth Geological Society, December 2, and before the Houston Geological Society, December 12.

The Midland Geological Society, Midland, Texas, has elected the following officers: president, B. A. RAY, Tide Water Associated Oil Company; vice-president, R. L. BATES, The Texas Company; secretary-treasurer, W. LLOYD HASELTINE, Magnolia Petroleum Company.

MARIUS ROBINSON CAMPBELL, honorary member of the Association, died at St. Petersburg, Florida, December 7, at the age of 82 years. He was long a member of the United States Geological Survey.

J. E. (BRICK) ELLIOTT has resigned from the Byron Jackson Company to pursue private work as a petroleum engineer at 3404 Yoakum Boulevard, Houston, Texas.

ANDREW MILEK, of the Consolidated Oil Corporation, New York, has moved to the Sinclair Prairie Oil Company at Tulsa, Oklahoma.

WALTER H. SPEARS has been appointed head of the geology and land departments of the Union Producing Company with headquarters in Shreveport, Louisiana.

JOHN SMITH IVY, who has served as vice-president and director, district manager, and head of the geology and land departments of the Union Producing Company, Houston, Texas, has resigned to devote his time to private interests.

The Houston Geological Society was recently addressed by E. BERL, research professor at Carnegie Institute of Technology, Pittsburgh, Pennsylvania, on the subject, "Origin of Coal and Oil."

A. K. MILLER, professor of geology at the University of Iowa, is the head of a field party into southern Mexico and northern Guatemala. Members of the party include M. L. THOMPSON, professor of geology and paleontology of the New Mexico School of Mines, and F. K. G. MÜLLERRIED of the geological department of Mexico University.

JOHN H. LOCK, of the Sinclair Prairie Oil Company, has moved from Tyler, Texas, to Baton Rouge, Louisiana.

R. B. DOWNING, consulting petroleum geologist of Wichita, Kansas, has been spending a large part of his time in the Falls City, Nebraska, area.

ARTHUR C. MUNYON, geologist of the Georgia Geological Survey, Atlanta, Georgia, addressed the Mississippi Geological Society, at Jackson, December 4, on "The Oil and Gas Possibilities and Stratigraphy of South Georgia."

E. FLOYD MILLER, geologist for the Oliphant Oil Corporation, Shreveport, Louisiana, talked before the South Louisiana Geological Society recently on "The Cotton Valley Field."

DONALD W. GRAVELL has moved from Houston, Texas, to Havana, Cuba, in care of the Atlantic Refining Company of Cuba, 401 Edificio La Metropolitana.

The Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, listened to W. W. LONGLEY, December 2, on the subject "Recent Developments in the Canadian Mining Industry and Its Relation to Canada's War Effort."

VICTOR H. KING, assistant geologist for the General Petroleum Corporation, has been transferred from Coalinga to Bakersfield, California.

CHARLES N. GOULD, Box 88, Norman, Oklahoma, is revising his book on *Oklahoma Place Names* published in 1933, and wishes to secure names of oil towns, especially those that once had a post office.

MARCEL SCHLUMBERGER, of Paris, and his brother CONRAD SCHLUMBERGER, who died in 1936, have been awarded the Anthony F. Lucas Gold Medal by the American Institute of Mining and Metallurgical Engineers for "distinguished achievement in improving the technique and practice of finding and producing petroleum."

H. B. STENZEL, of the University of Texas Bureau of Economic Geology at Austin, Texas, spoke before the South Texas Geological Society at Corpus Christi, November 15, on "Sedimentation Problems of the Texas Coast Eocene."

J. TERRY DUCE, formerly of New York, has moved to San Francisco, California, to assume duties as vice-president of the California Arabian Standard Oil Company.

ROBERT H. ROBIE, of the Shell Oil Company, Inc., San Antonio, Texas, talked recently on "The Wilcox of Southwest Texas," before the Houston Geological Society.

MARGARET FULLER BOOS, associate professor of geology at the University of Denver, spent August in Central American countries, making geological and geographical studies, chiefly in Guatemala. In Guatemala she measured a section across the Sierra de las Minas from Guatemala City to Coban. In Honduras she spent some time at Rosario in the largest silver mines of the world.

JAY P. WOOD, consulting mining engineer of Denver, Colorado, is back home after an absence of five months. He is associated with the firm of Hamilton, Beauchamp and Woodworth, metallurgical engineers, of San Francisco, California.

W. A. J. M. van Waterschoot van der Gracht, honorary member of the Association, has sent several messages from his home in the Netherlands. The following card is here printed as of interest to his many friends.

Dear Mr. DeGolyer,

Many thanks for the reprint of your interesting C. F. Brackett Lecture at Princeton on the Development of the Art of Prospecting. Mails are slow and uncertain in these miserable days, but I am glad it reached me all right! Mrs. van der Gracht and myself are as well as circumstances permit, which are not cheerful. But I make myself as useful as possible by assisting geological students and young mining engineers, to get useful practice by such exploratory work, chiefly geophysical, as this country still requires. I retired from the direction of the Mining Service two years over age-limit, but I am happy to be still useful. We found that apparently monotonous Holland is appallingly diversified and even precipitous at moderate depths, notably below the Gault, but already below the Miocene. So the work is interesting enough. It is the geology of England, but buried under a few hundreds to 3,000 feet of upper Tertiary and Pleistocene. Below that, anything is possible in a strongly faulted and folded underground!

Please give my sincere regards to all friends of an old and happier time in peaceful United States. All I can wish you all is "peace"!

Cordially yours,
V. Waterschoot v. d. Gracht

Huize Jachtduin
36 Eeuwige Laan, Bergen, N. H.,
Netherlands
October 20, 1940

Ray C. Lewis, of the Stanolind Oil and Gas Company, has moved from San Antonio to Houston, Texas.

C. E. Dobbin, of the United States Geological Survey, talked before the Rocky Mountain Association of Petroleum Geologists, at Denver, Colorado, December 16, on "The Committee Report on Possible Petroliferous Areas in the Rocky Mountain Region."

Jerome J. O'Brien, of the Sunset Oil Company, has been transferred from the Corpus Christi, Texas, office to the head office in Los Angeles, California, and has been promoted to the position of chief geologist.

L. C. Snider, president of the Association, visited the Michigan Geological Society at Lansing, and the Illinois Geological Society at Champaign, in early December.

J. G. Crawford, of the United States Department of the Interior, has moved from Midwest to 402 South Jackson Street, Casper, Wyoming. The chemical laboratory of the Geological Survey was moved to the Federal Building, Casper, last October.

The Kansas Geological Society, Wichita, Kansas, has elected the following officers: president, John W. Inkster, Shell Oil Company, Inc.; vice-president, J. P. McKee, consulting geologist; secretary-treasurer, Lee H. Cornell (re-elected), Stanolind Oil and Gas Company. The Society meets on the first Tuesday of each month, in the Geological Room at the University of Kansas.

Thurman H. Myers, secretary of the Appalachian Geological Society, died on December 9 at the age of 50 years. He was chief engineer and geologist for the Carnegie Natural Gas Company, Pittsburgh, Pennsylvania.

A. P. LOSKAMP has resigned his position as manager of geological and leasing activities of the Barnsdall Oil Company at Midland, Texas, to accept a similar position with the Union Oil Company of California at Midland. J. D. MCCLURE has succeeded Loskamp in the Barnsdall office.

PHIL D. HELMIG, of the Gulf Oil Corporation, has moved from Bismarck, North Dakota, to 107 South Ash Street, Carlsbad, New Mexico.

CLYDE O. HUDGENS, of the Gulf Oil Corporation, has moved from Jasper, Indiana, to Tulsa, Oklahoma.

E. E. ROSAIRE, of Subterrex, Houston, Texas, addressed the Tulsa Geological Society, at Kendall Hall, Tulsa University, December 16, on the subject, "The Analysis of the Refraction Collapse of 1930."

FRANK A. HERALD has changed his address from Austin, Texas, to Ebasco Services, Incorporated, 2 Rector Street, New York. Since September 1 he has been with Ebasco as assistant operating sponsor. In this capacity he serves as consultant to the subsidiaries of Electric Bond and Share Company which produce oil and gas, which includes companies operating in Texas, Louisiana, Mississippi, Montana, and Pennsylvania. Since his work at present is mainly in Texas and Louisiana, he has not yet moved his residence to New York.

JEROME M. WESTHEIMER, of the Simpson-Fell Oil Company, gave a paper on Montague County before the Ardmore, Oklahoma, Geological Society, January 7.

ALDEN W. FOSTER, formerly of Ralph E. Davis, Inc., has opened his office as petroleum engineer at 2247 Oliver Building, Pittsburgh, Pennsylvania. R. H. SMITH is associated with Foster, to engage in the business of dealing in producing oil and gas properties and royalties.

LOUIS WALLACE has been transferred from Grayville, Illinois, to Midland, Texas. His address is The Superior Oil Company, Box 510, Midland.

ERNEST A. OBERING, who resigned from the Shell Oil Company, Inc., last May, is an independent producer. He recently opened a new field in the Woodlawn area of Jefferson County, Illinois, discovered on subsurface data.

A. E. FATH has returned from Spain. He may be addressed in care of the Socony-Vacuum Oil Company, Inc., 26 Broadway, New York City.

IRA BRINKERHOFF, of the Stanolind Oil and Gas Company, has moved from Houston, Texas, to 910 South Michigan Avenue, Chicago, Illinois.

The fifty-third annual meeting of the Geological Society of America was held at the University of Texas at Austin, December 26–28 with president ELIOT BLACKWELDER, Stanford University, presiding. Approximately 750 geologists and guests registered. NELSON HORATIO DARTON, for many years geologist with the United States Geological Survey, was awarded the Penrose medal of the Society for his outstanding work in geology. Officers for the new year are: president, CHARLES P. BERKEY, Columbia University, New York; vice-presidents, GEORGE S. HUME, Geological Survey of Canada, Toronto, RAYMOND C. MOORE, Kansas Geological Survey, Lawrence, WILLIAM F.

FOSHAG, United States National Museum, Washington, D. C.; secretary, H. R. ALDRICH, New York City; treasurer, EDWARD B. MATHEWS, Johns Hopkins University, Baltimore. The Mineralogical Society of America elected as president FRED C. WRIGHT, of the Carnegie Institute Geophysical Laboratory, Washington, D. C. The Paleontological Society elected L. W. STEPHENSON, of the United States Geological Society, Washington, D. C. as its president.

The American Association for the Advancement of Science, Section E (Geology and Geography) held joint meetings with the Geological Society of America, with Section B (Physics), with the American Physical Society, with the Philadelphia Geological Society, and with the Association of American Geographers at Philadelphia, Pennsylvania, December 27–30. HUGH D. MISER, of the United States Geological Survey, presided as vice-president and chairman of the Section.

The Appalachian Geological Society, Charleston, West Virginia, has elected officers for 1941 as follows: president, J. R. LOCKETT (re-elected), Ohio Fuel Gas Company, Columbus, Ohio; vice-president, CHARLES BREWER, JR. (re-elected), of Godfrey L. Cabot, Inc., Charleston, West Virginia; secretary-treasurer, J. E. BILLINGSLEY, West Virginia Gas Corporation, Charleston; editor, ROBERT C. LAFFERTY (re-elected), Owens, Libbey-Owens Gas Department, Charleston.

JOHN L. RICH, head of the department of geology and geography at the University of Cincinnati, addressed the Tulsa Geological Society, at Kendall Hall, Tulsa University, January 6, on "Tupungato Field of Argentina and Structure of the Andes Mountains."

C. WINTHROP PAYNE is with the Carter Oil Company at Winnfield, Louisiana.

G. E. HIGGINS, formerly with the Caracas Petroleum S. A., in Venezuela, is with the Trinidad Leaseholds, Ltd., Port of Spain, Trinidad, B.W.I.

R. O. RHOADES, of the Gulf Oil Corporation, has returned from London. His address is Box 1166, Pittsburgh, Pennsylvania.

CARL WEIDMANN has changed his address from Ciudad Trujillo, Republica Dominica, to Box A 185, Port-au-Prince, Haiti.

ROBERT L. BATES, recently with The Texas Company at Midland, Texas, may be addressed in care of the New Mexico School of Mines, Socorro, New Mexico.

F. W. ROLSHAUSEN, chief paleontologist for the Humble Oil and Refining Company, discussed "Bottom Deposits and Associated Organisms in the Gulf of Mexico" before the Houston Geological Society, December 31.

M. A. J. SMITH, who has been working for the Texas Petroleum Company in Bogota, Colombia, has returned to the United States. His address is 114 North Main Street, Mount Pleasant, Iowa.

F. H. AGEE has moved from Columbus, Mississippi, to Longview, Texas.

OKLAHOMA

ELFRED BECK
Geologist

717 McBirney Bldg.
TULSA, OKLA.

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DALLAS, TEX.

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A. I. LEVORSEN

Petroleum Geologist

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TULSA OKLAHOMA

G. H. WESTBY

Geologist and Geophysicist
Seismograph Service Corporation

Kennedy Building Tulsa, Oklahoma

PENNSYLVANIA

HUNTLEY & HUNTLEY
Petroleum Geologists
and Engineers

L. G. HUNTLEY
J. R. WYLIE, JR.
Grant Building, Pittsburgh, Pa.

TEXAS

JOSEPH L. ADLER
Geologist and Geophysicist

Consultant and Contractor in Geological and Geophysical Exploration

2011 Esperson Bldg.
HOUSTON, TEXAS

D'ARCY M. CASHIN
Geologist *Engineer*
Specialist, Gulf Coast Salt Domes

Examinations, Reports, Appraisals
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DENVER, COLORADO

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2nd Vice-President - - - - - - Ninetta Davis
224 U. S. Customs Building
Secretary-Treasurer - - - - - Dart Wantland
927 Humboldt Street

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - John W. Inkster
Shell Oil Company, Inc.
Vice-President - - - - - - - - J. P. McKee
Consulting Geologist
Secretary-Treasurer - - - - - Lee H. Cornell
Stanolind Oil and Gas Company
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - W. A. Clark
Michigan Elevation Service, Box 192, Mt. Pleasant
Vice-President - - - - - - - - W. F. Brown
Mt. Pleasant
Secretary-Treasurer - - - - - C. H. Riggs
Michigan Geological Survey
21 Sheldon, N.E., Grand Rapids
Business Manager - - - - - S. G. Bergquist
Michigan State College, East Lansing

Meetings: Monthly dinner meetings rotating between Saginaw, Mt. Pleasant, and Lansing. Informal dress.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - Melville W. Fuller
Carter Oil Company, Mattoon, Box 568

Vice-President - - - - - Maxwell B. Miller
The Texas Company, Mattoon

Secretary-Treasurer - - - James G. Mitchell
The Pure Oil Company, Clay City

Meetings will be announced.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - Warren B. Weeks
Phillips Petroleum Co., 1009 Giddens-Lane Bldg.
Vice-President - - - - Weldon E. Cartwright
Tide Water Associated—Seaboard Oil Cos.
Secretary-Treasurer - - - - - - - S. C. Giesey
Stanolind O. & G. Co., 519 Commercial Natl. Bank Bldg., Box 1092
Historian - - - - - - - - - - Robert B. Totten
Phillips Petroleum Company

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - H. V. Tygrett
Atlantic Refining Company
Vice-President - - - - - - - - - Coe Mills
Ohio Oil Company, Lafayette, Louisiana
Secretary - - - - - - - - - E. M. Baysinger
Box 210
Treasurer - - - - - - - - - - Baker Hoskins
Shell Oil Company, Inc., Box 598

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - - Urban B. Hughes
Consulting Geologist, 605 Tower Building
Vice-President - - - - - - Tom McGlothlin
Gulf Refining Company, Box 1105
Secretary-Treasurer - - - - David C. Harrell
Carter Oil Company, Box 1490

Meetings: First and third Wednesdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - W. Morris Guthrey
The Texas Company, Box 539
Vice-President - - - - - - Paul L. Bartram
Phillips Petroleum Company
Secretary-Treasurer - - - - - Tom L. Coleman
U. S. Geological Survey, Box 719

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - Albert S. Clinkscales
Consulting Geologist, Colcord Building
Vice-President - - - - - - - Clyde H. Dorr
Hall-Briscoe, Inc., 2118 First National Bldg.
Secretary-Treasurer - - - - - F. Mabry Hoover
Empire Oil & Refg. Company, Box 4577

Meetings, Ninth Floor, Commerce Exchange Building: Technical Program, second Monday, each month, 8:00 P.M.; Luncheons, every Monday, 12:15 P.M.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - - - M. C. Roberts
The Texas Company
Vice-President - - - - - Robert L. Cassingham
Amerada Petroleum Corporation
Secretary-Treasurer - - - - - M. D. Hubley
Stanolind Oil and Gas Company

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA
TULSA, OKLAHOMA

President - - - - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation, Box 2040
Vice-President - - - - - - - Wendell S. Johns
The Texas Company
Secretary-Treasurer - - - - - Floyd L. Swabb
Sun Oil Company, Box 1348

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - Joseph L. Borden
The Pure Oil Company, Box 271
1st Vice-President - - - - - John G. Bartram
Stanolind Oil and Gas Company
2nd Vice-President - - - - - Ronald J. Cullen
Sun Oil Company
Secretary-Treasurer - - - - - Herbert H. Kister
Stanolind Oil and Gas Company, Box 591
Editor - - - - - - - - - - - John L. Ferguson
Amerada Petroleum Corporation
Associate Editor - - - - - - Hiram J. Tandy
Route 7

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday (October-May), Michaelis Cafeteria, 507 South Boulder Avenue.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - - W. W. Clawson
Magnolia Petroleum Company, Box 900
Vice-President - - - - Lewis W. MacNaughton
DeGolyer, MacNaughton, and McGhee
Secretary-Treasurer - - - D. M. Collingwood
Sun Oil Company, Box 2880
Executive Committee - - - Paul W. McFarland

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - Frank R. Denton
Stanolind Oil and Gas Company
Vice-President - - - - - - - C. I. Alexander
Magnolia Petroleum Company, Box 780
Secretary-Treasurer - - - - - -G. J. Loetterle
Shell Oil Company, Inc., Box 2037

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - Ralph S. Powell
The Texas Company, Box 1720

Vice-President - - - - - Louis H. Freedman
Snowden and McSweeney Company

Secretary-Treasurer - - - - - Vernon Lipscomb
The Pure Oil Company, Box 2107

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - George S. Buchanan
Consulting Geologist, Esperson Building

Vice-President - - - - - - - - A. P. Allison
Sun Oil Company, Box 2659

Secretary - - - - - - - - - - - Leslie Bowling
Union Oil Company of California
1134 Commercial Building

Treasurer - - - - - - - - - Dugald Gordon
Brokaw, Dixon, and McKee, Gulf Building

Regular meeting held every Thursday at noon (12 o'clock) above Kelly's Restaurant, 910 Texas Avenue. For any particulars pertaining to the meetings write of call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - - - - J. R. Seitz
Seitz, Comegys, and Seitz, 531 Waggoner Building

Vice-President - - - - - - - J. J. Russell, Jr.
Sinclair Prairie Oil Company
509 Hamilton Building

Secretary-Treasurer - - - - - - - J. M. Clark
Tide Water Associated Oil Company
924 Hamilton Building

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO AND CORPUS CHRISTI TEXAS

President - - - - - - - - - - Fred P. Shayes
United Gas Company, Beeville

Vice-President - - - - - - - - - Gentry Kidd
Stanolind Oil and Gas Company, San Antonio

Secretary-Treasurer - - - - - Robert N. Kolm
1742 Milam Building, San Antonio

Executive Committee - - - - - - L. W. Storm

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

SOUTHWESTERN GEOLOGICAL SOCIETY
AUSTIN, TEXAS

President - - - - - - - - - - - H. B. Stenzel
Bureau of Economic Geology

Vice-President - - - - William A. Bramlette
Univ. Texas, Dept. of Geology

Secretary-Treasurer - - - - - - - Travis Parker
Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - John Emery Adams
Standard Oil Co. of Texas, Box 71, Gretna, La.

Vice-President - - - - - - - - Dana M. Secor
Skelly Oil Company

Secretary-Treasurer - - - - - Fred F. Kotyza
Tide Water Associated Oil Company, Box 181

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 1435

President - - - - - - - - - - J. R. Lockett
Ohio Fuel Gas Co., Box 117, Columbus, Ohio

Vice-President - - - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348, Charleston, W.Va.

Secretary-Treasurer - - - - - - J. E. Billingsley
West Virginia Gas Corporation
Box 404, Charleston, W.Va.

Editor - - - - - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department
Box 1375, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - - - W. T. Born
Geophysical Research Corporation
Box 2040, Tulsa, Oklahoma

Vice-President - - - - - - - - H. B. Peacock
Geophysical Service, Inc., Houston, Texas

Editor - - - - - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Secretary-Treasurer - - - - - Andrew Gilmour
Amerada Petroleum Corporation
Box 2040, Tulsa, Oklahoma

Past-President - - - - - - - - E. A. Eckhardt
Gulf Research and Development Company
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Business Manager - - - - - - - J. F. Gallie
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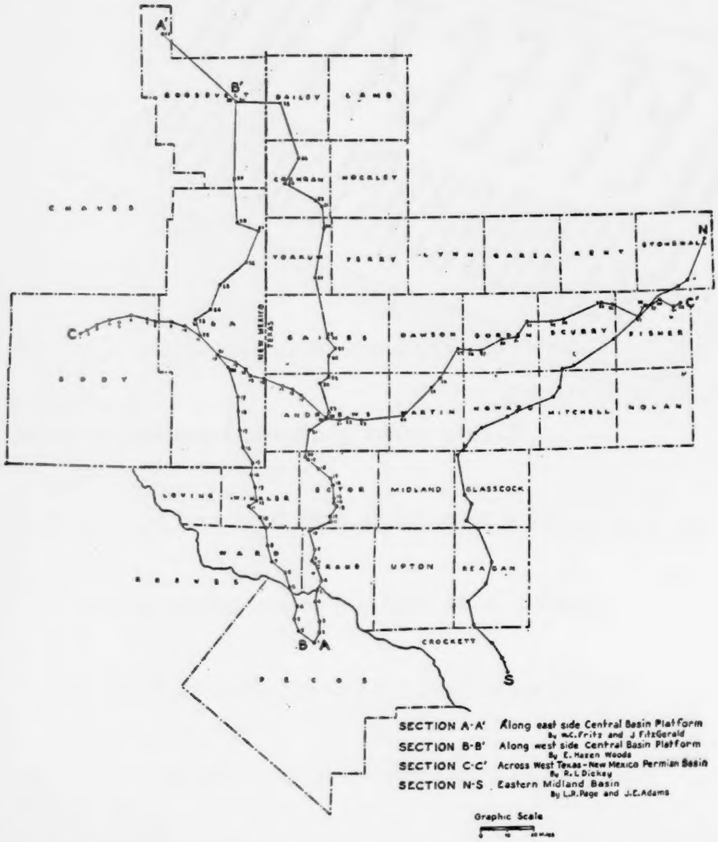
REGIONAL CROSS SECTIONS
WEST TEXAS-NEW MEXICO PERMIAN BASIN



Announcement of these West Texas-New Mexico stereograms and cross sections, made in the January, 1940, Bulletin, is here repeated for those who desire to take advantage of this offer. These sections, shown only in skeleton or reduced form in the West Texas-New Mexico symposium, are available as blue-line paper prints, *with complete, original stratigraphic details not shown in the Bulletin.*

	PRICES POSTPAID	
	To A.A.P.G.	*To Others*
LEWIS STEREOGRAMS (Jan. Bulletin p. 13). Vertical scale, 1 in. = 1,000 ft. Set of 3 sheets 72 x 42; 48 x 40; 32 x 20 in.	$3.35	$4.25
SECTION AA, (Jan. Bull. p. 16). Scale, 1 in. = 4 mi. 84 x 21 in.	1.35	1.70
SECTION BB, (Jan. Bull. p. 30). Scale, 1 in. = 4 mi. 72 x 20 in.	1.10	1.35
SECTION CC, (Jan. Bull. p. 38). Scale, 1 in. = 4 mi. 75 x 27 in.	1.40	1.80
SECTION NS, (Jan. Bull. p. 56). Scale, 1 in. = 4 mi. 36 x 24 in.	0.70	0.85

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA, OKLAHOMA, U.S.A.